Defense Threat Reduction Agency

Single-Event Effects Induced by Two-Photon-Absorption:

Overview and Current Status

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Outline

- Laser-Induced Single-Event Effects (SEEs)
- The Two-Photon Absorption (TPA) SEE Experiment
- 3-D Mapping of Single-Event Transients (SETs) in the LM124
- Backside “Through-Wafer” Carrier Injection
- Conclusions

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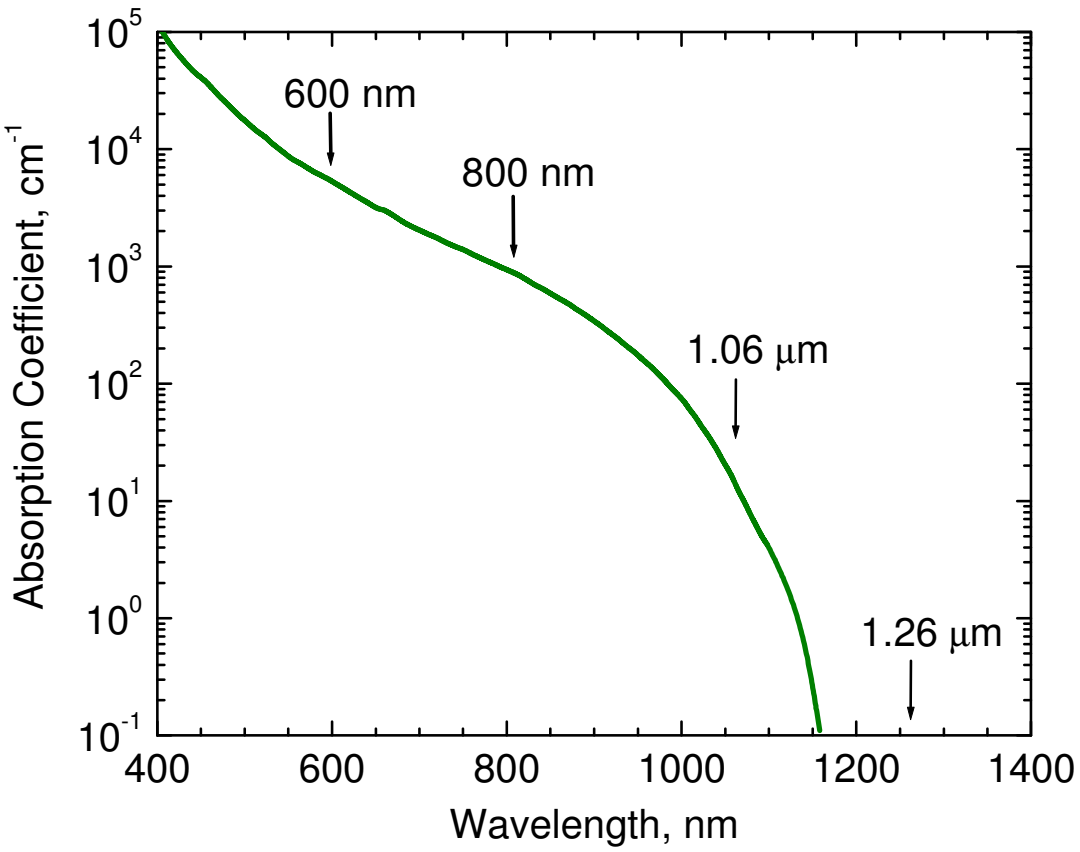
Pulsed Picosecond Laser

- Indispensable tool for SEE characterization
- Above-band gap pulsed laser can inject:
  - a well-characterized quantity of charge
  - in a well-defined location
  - at a well-defined time
  - with a well-defined charge-deposition profile

Two-Photon Absorption SEE Experiment



- Because the laser pulse wavelength is sub-bandgap the material is *transparent* to the optical pulse
- Carriers are generated by nonlinear absorption at high pulse irradiances by the simultaneous absorption of two photons
- Carriers are highly concentrated in the high irradiance region near the focus of the beam
- Because of the lack of exponential attenuation, carriers can be injected at any depth in the semiconductor material
- This permits 3-D mapping and backside illumination

Two-Photon Absorption SEE Experiment

Carrier generation equation:

$$\frac{dN(r,z)}{dt} = \frac{\alpha I(r,z)}{\hbar\omega} + \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$

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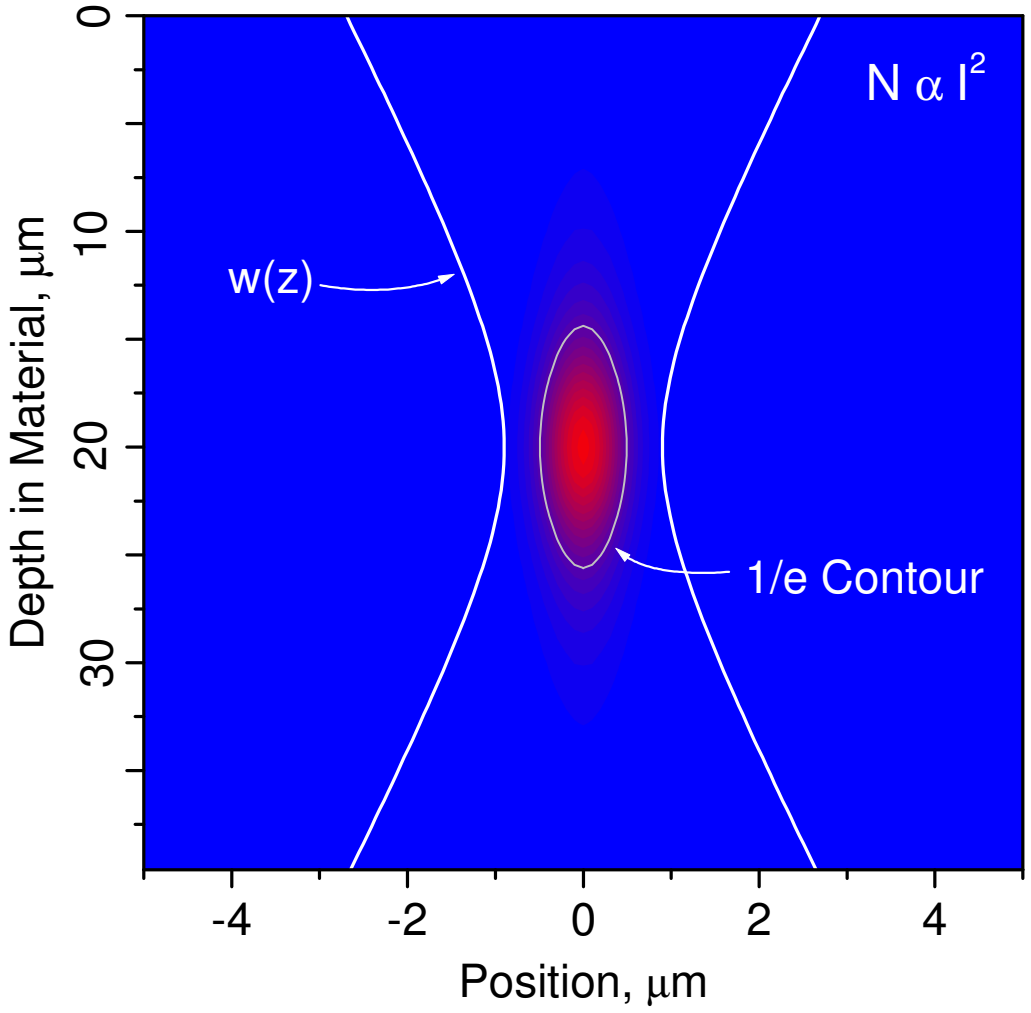

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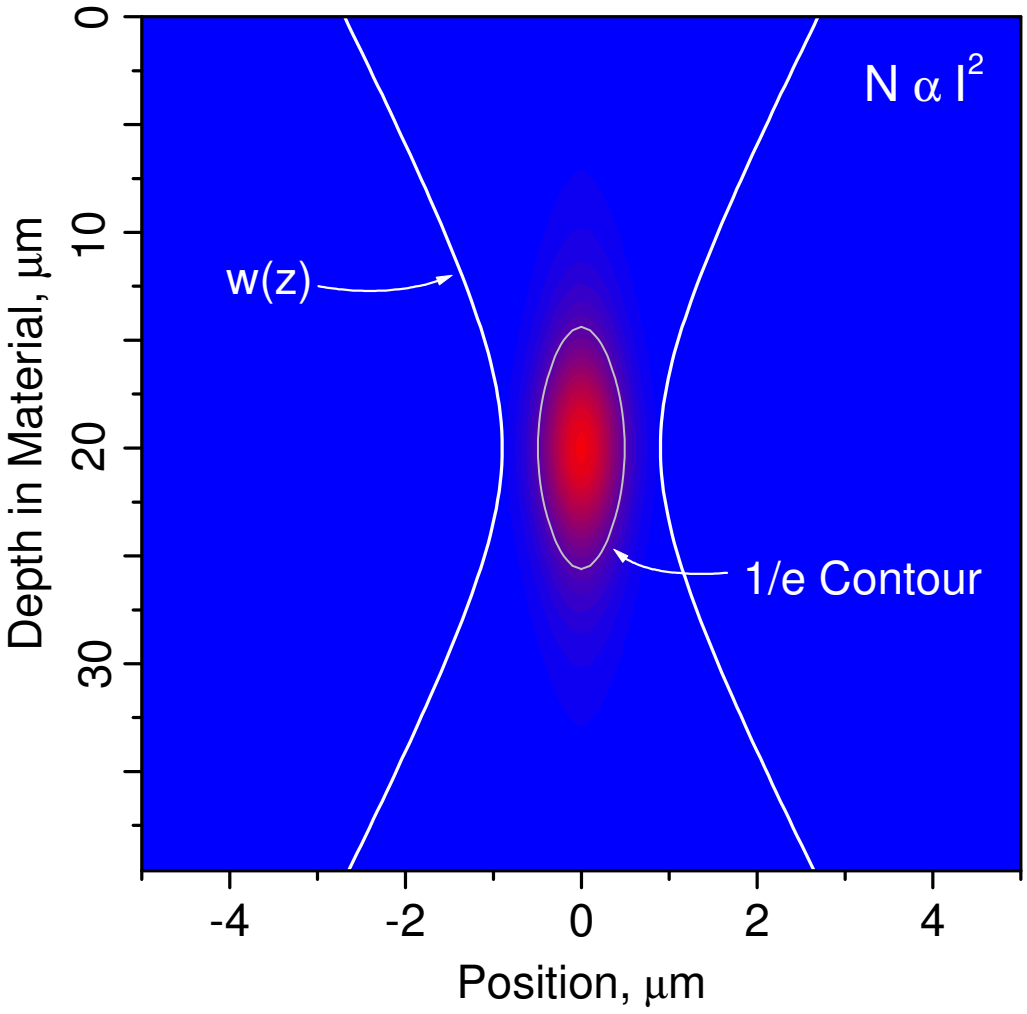

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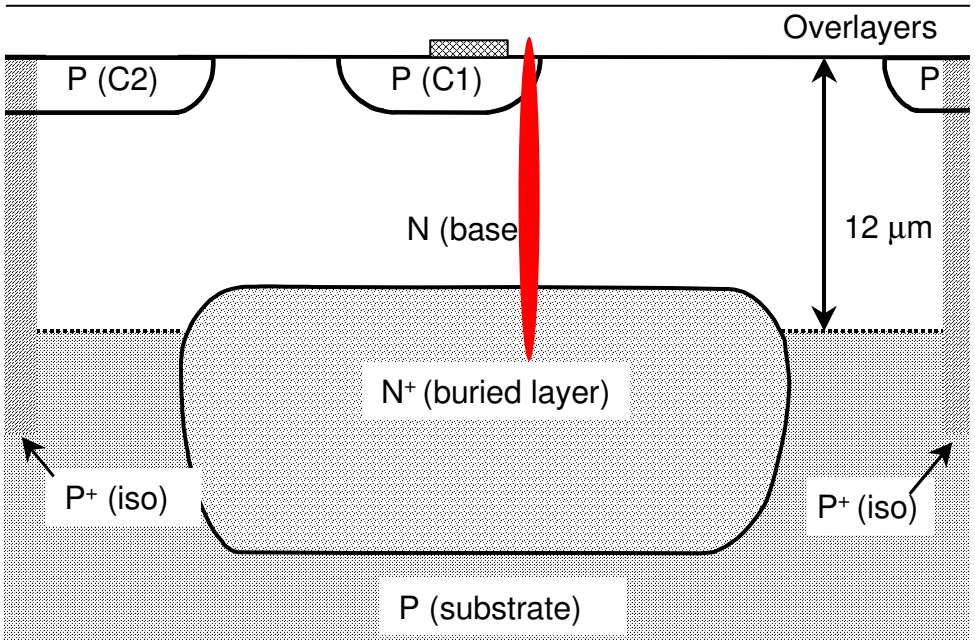

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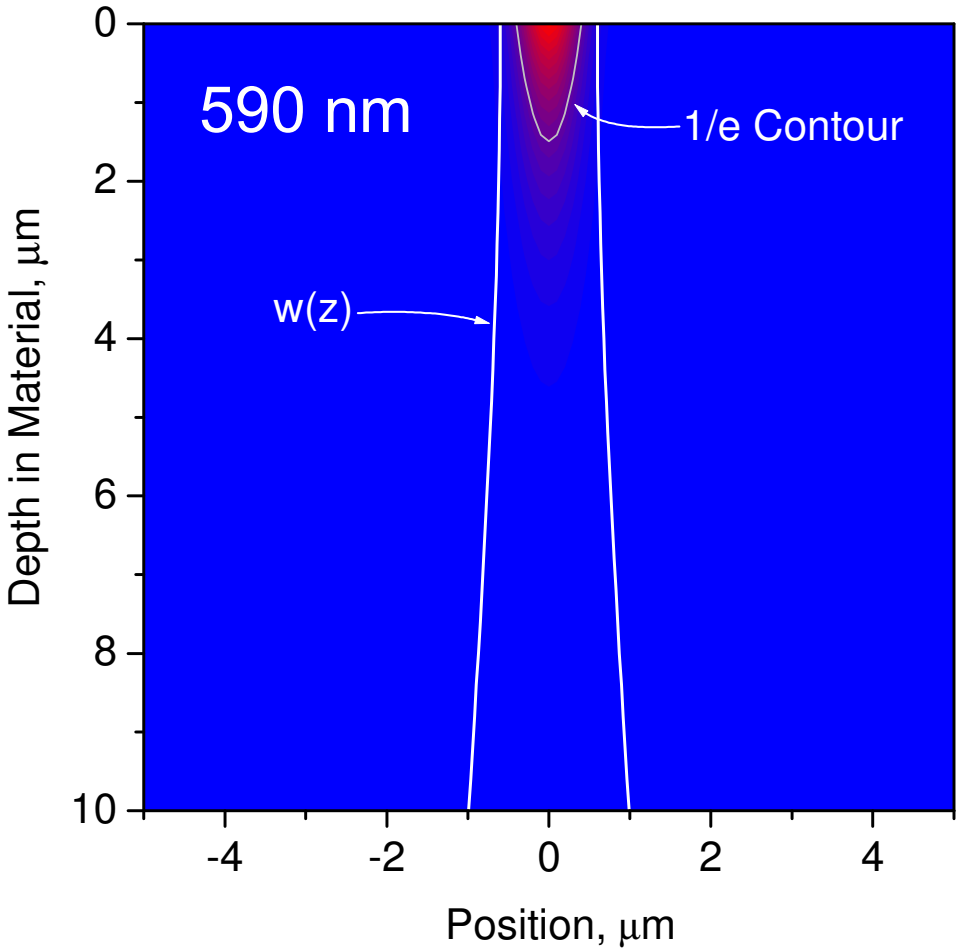

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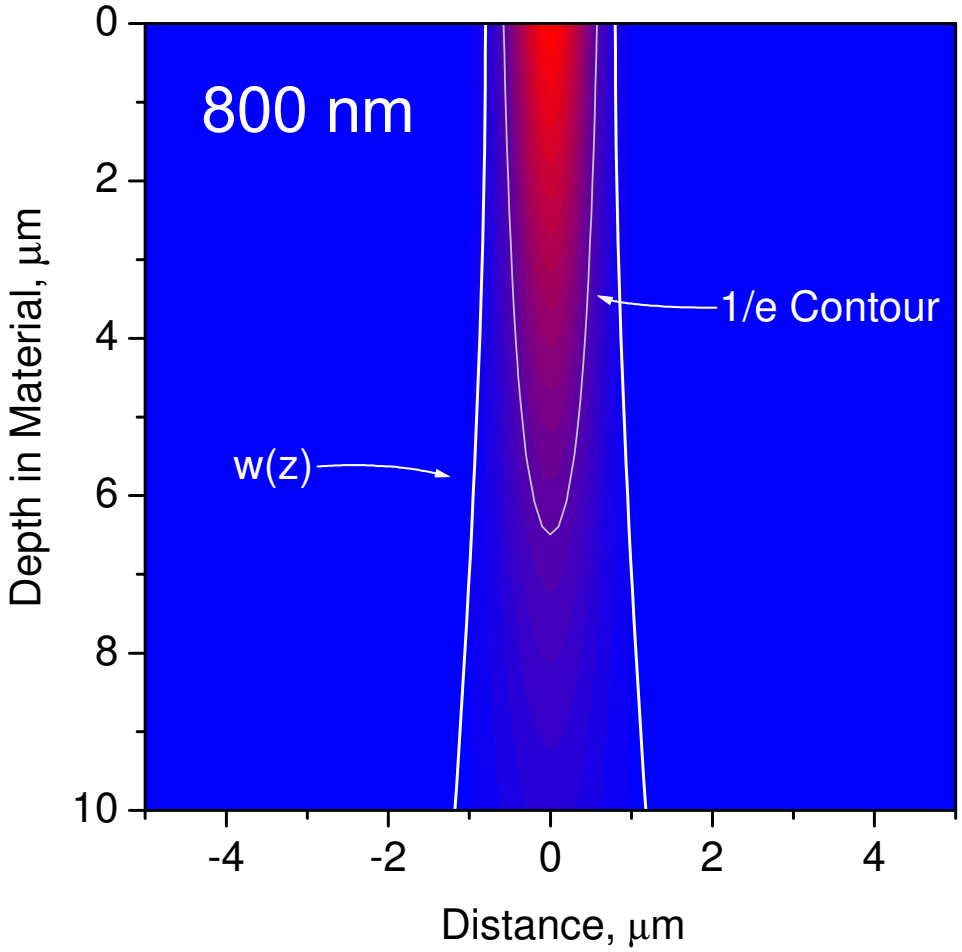

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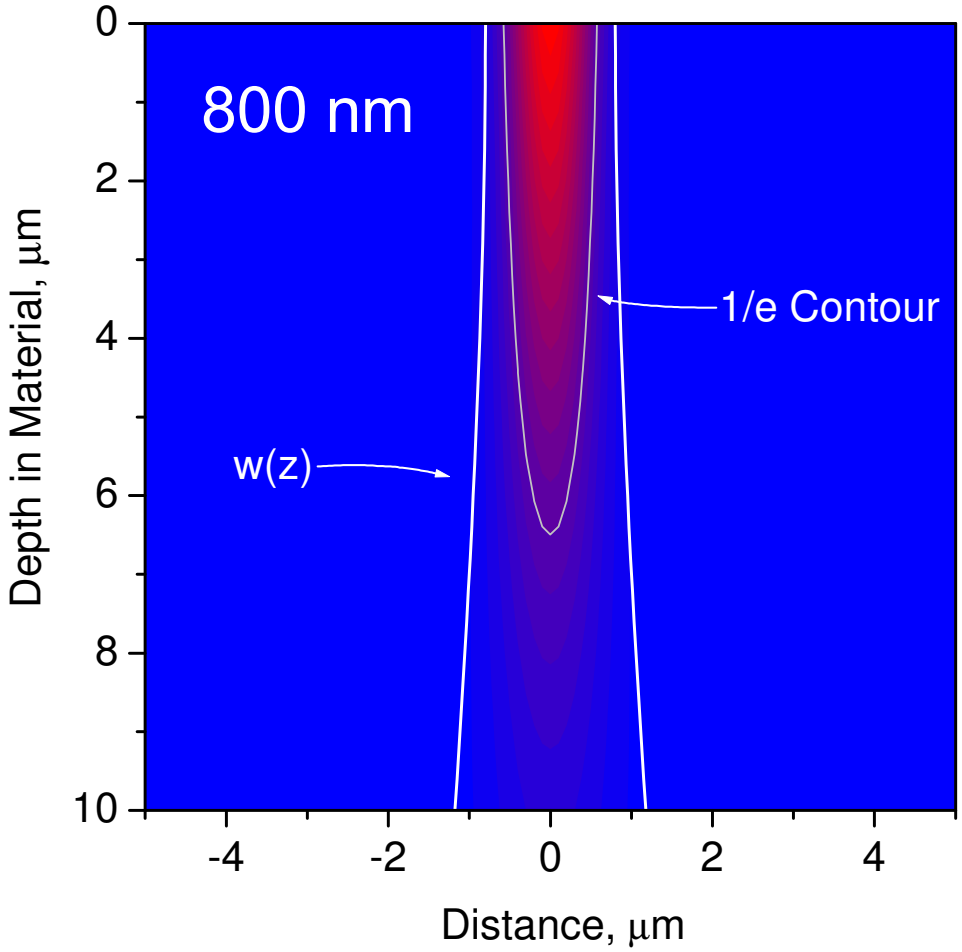

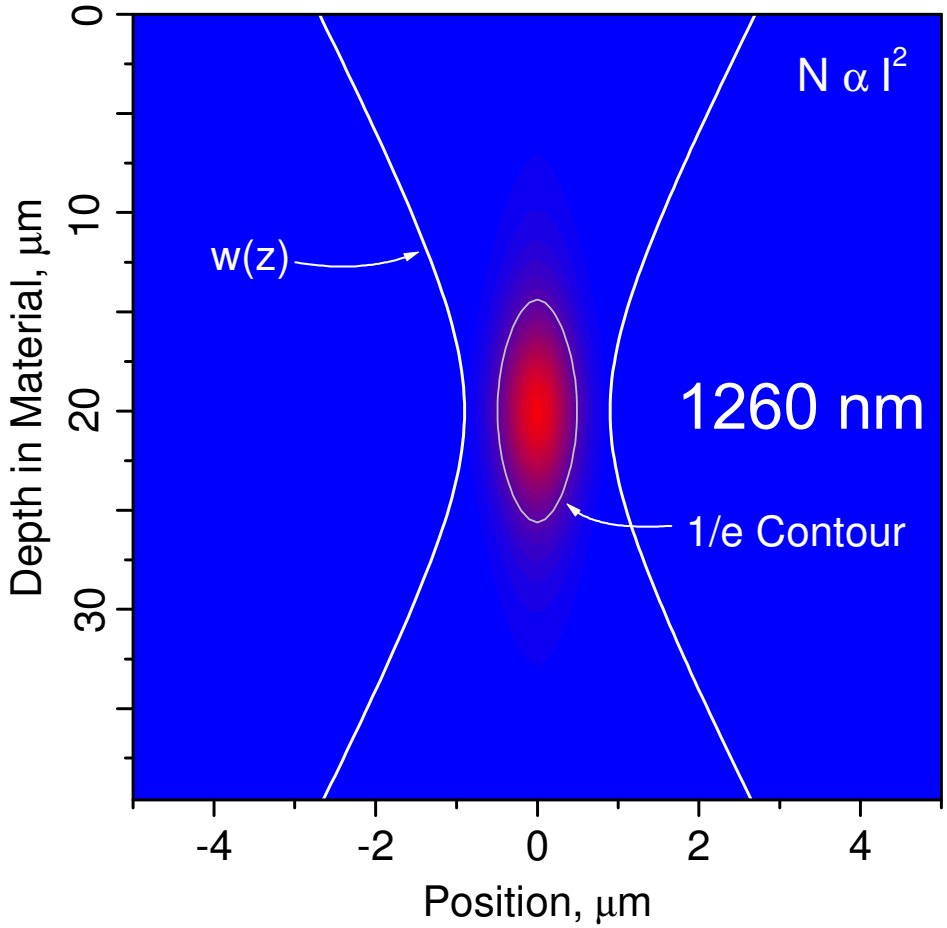

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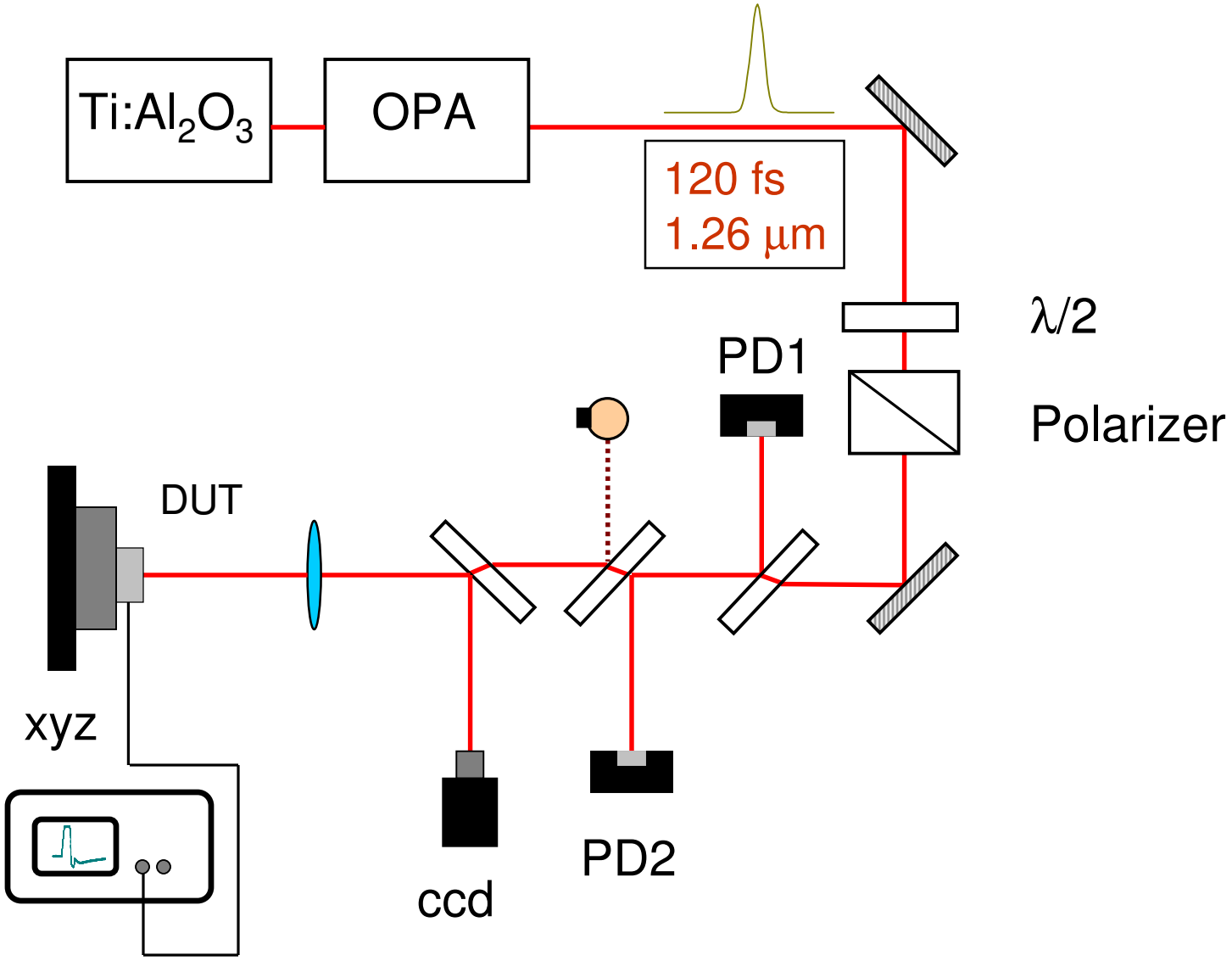
Two-Photon Absorption SEE Experiment

COMPLEMENTARY TECHINQUE

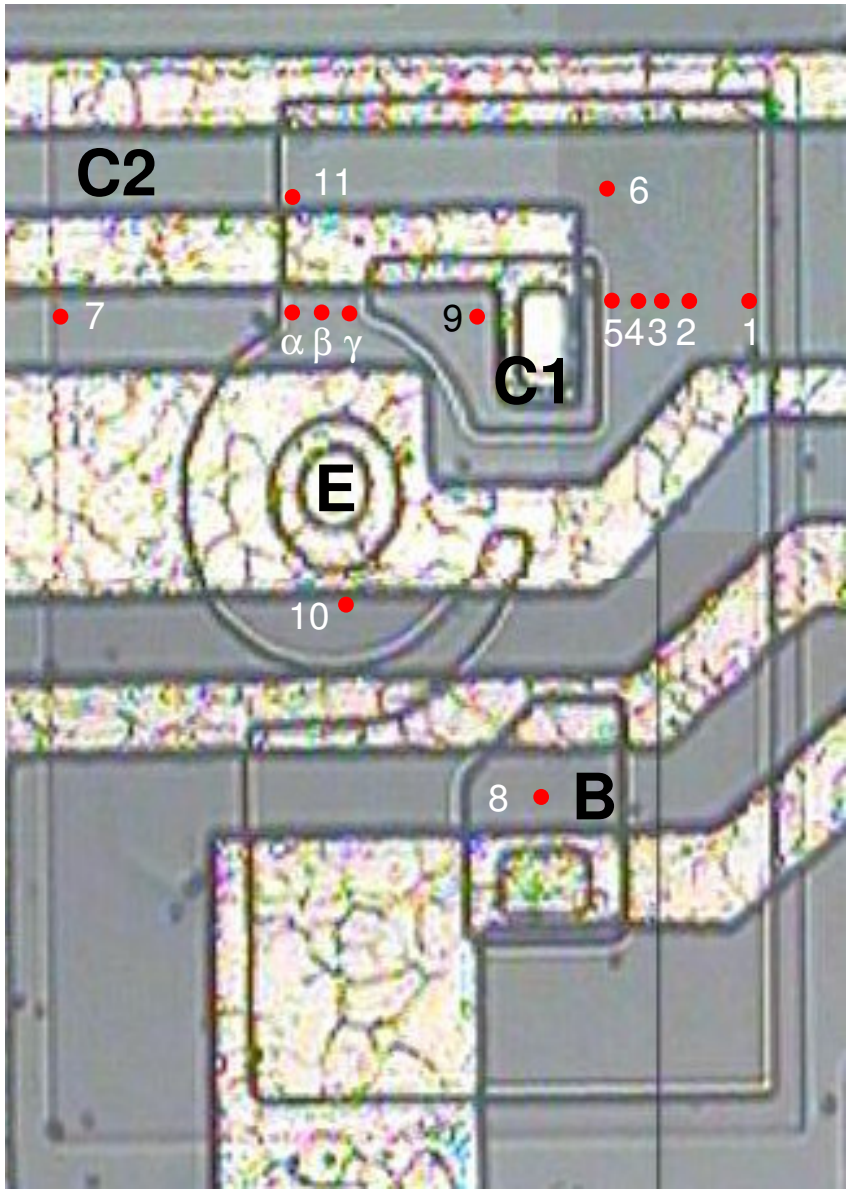
- Not intended to replace “conventional” (above band gap) pulsed laser
- Not intended to replace heavy-ion irradiation
- WILL NOT replace these tools
- Is another “Tool” in our “SEE Toolbox”

Two-Photon Absorption SEE Experiment



Three-Dimensional Mapping of SEE Sensitivity

(LM124 Q20: General Characteristics)



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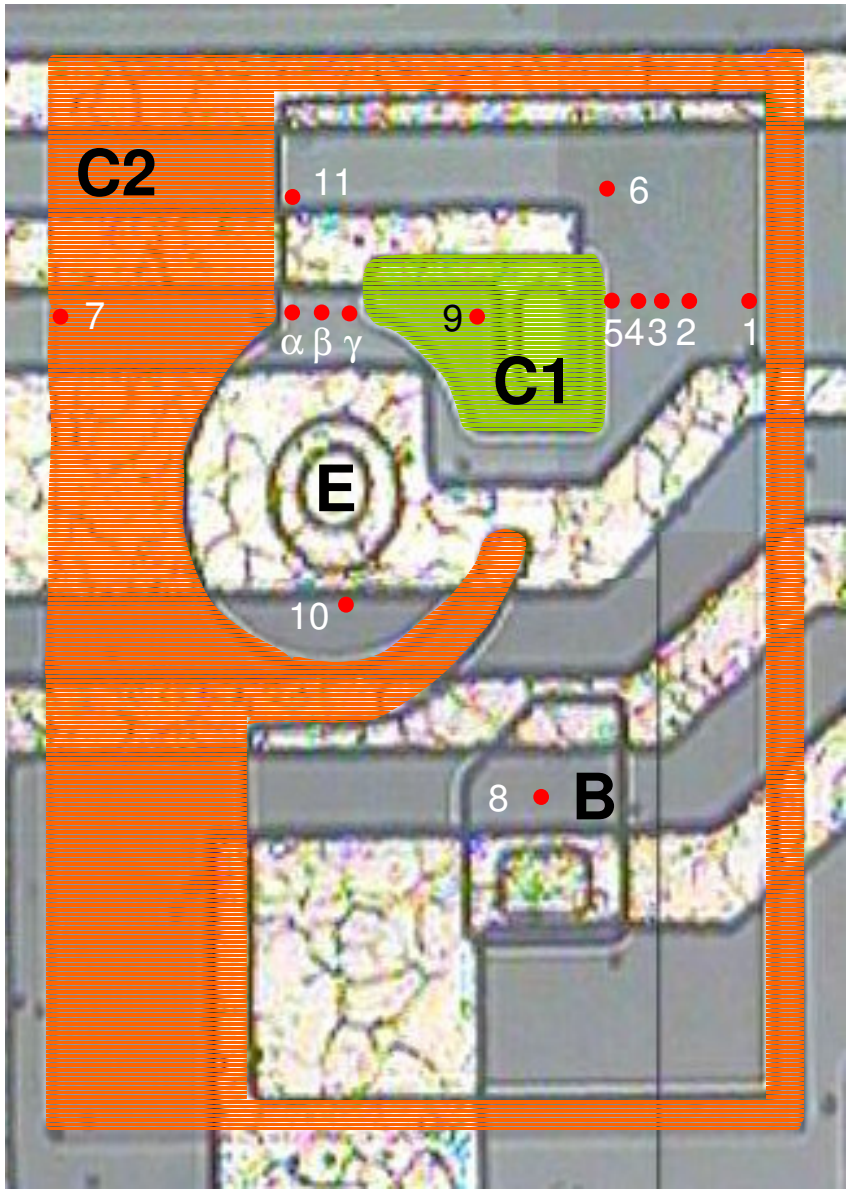

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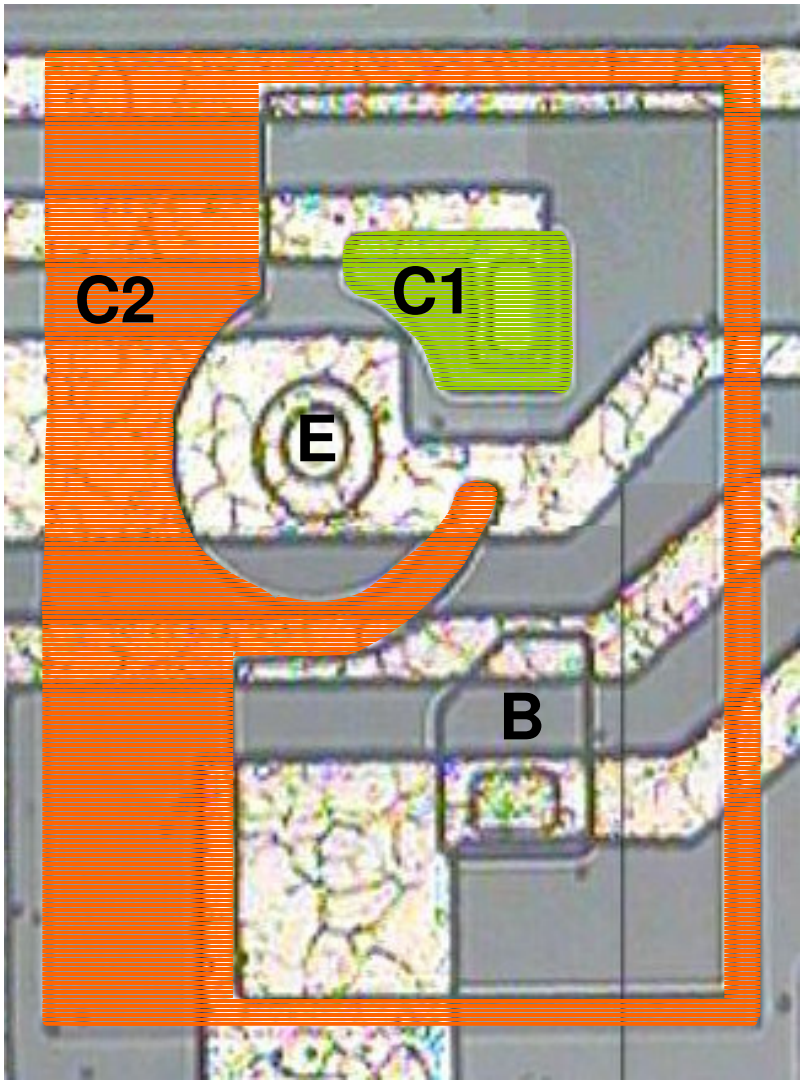
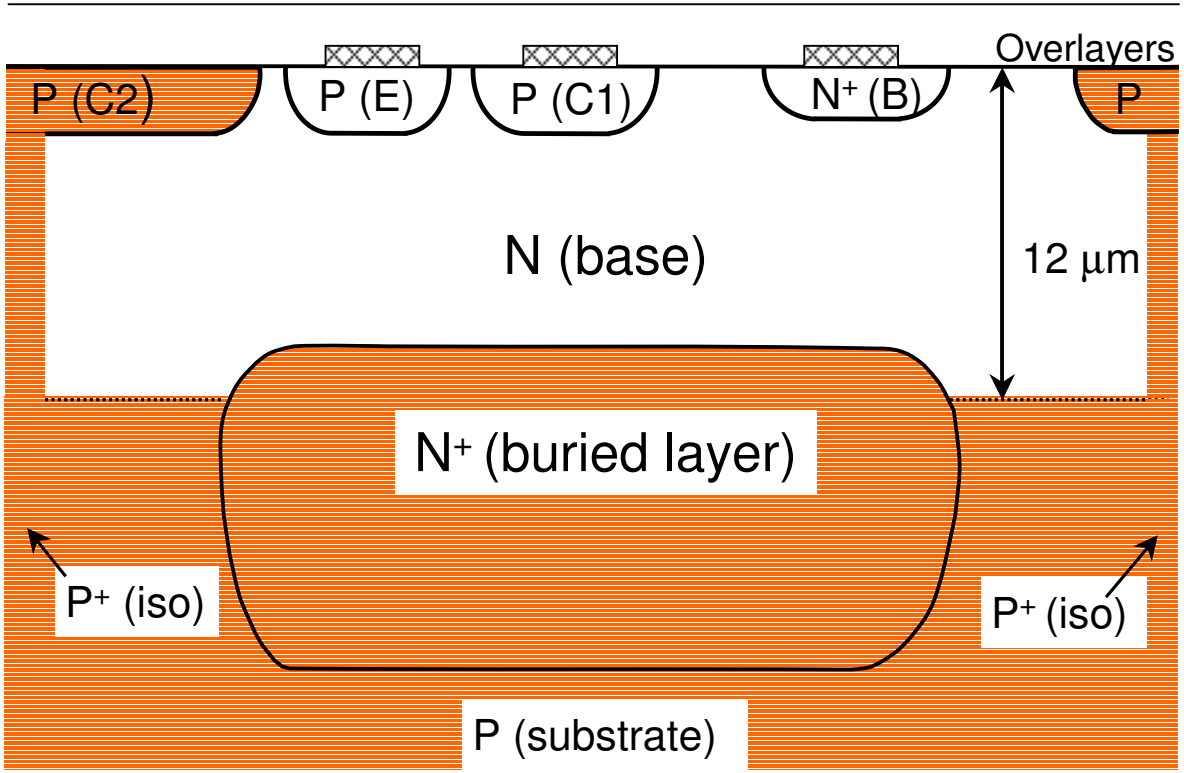
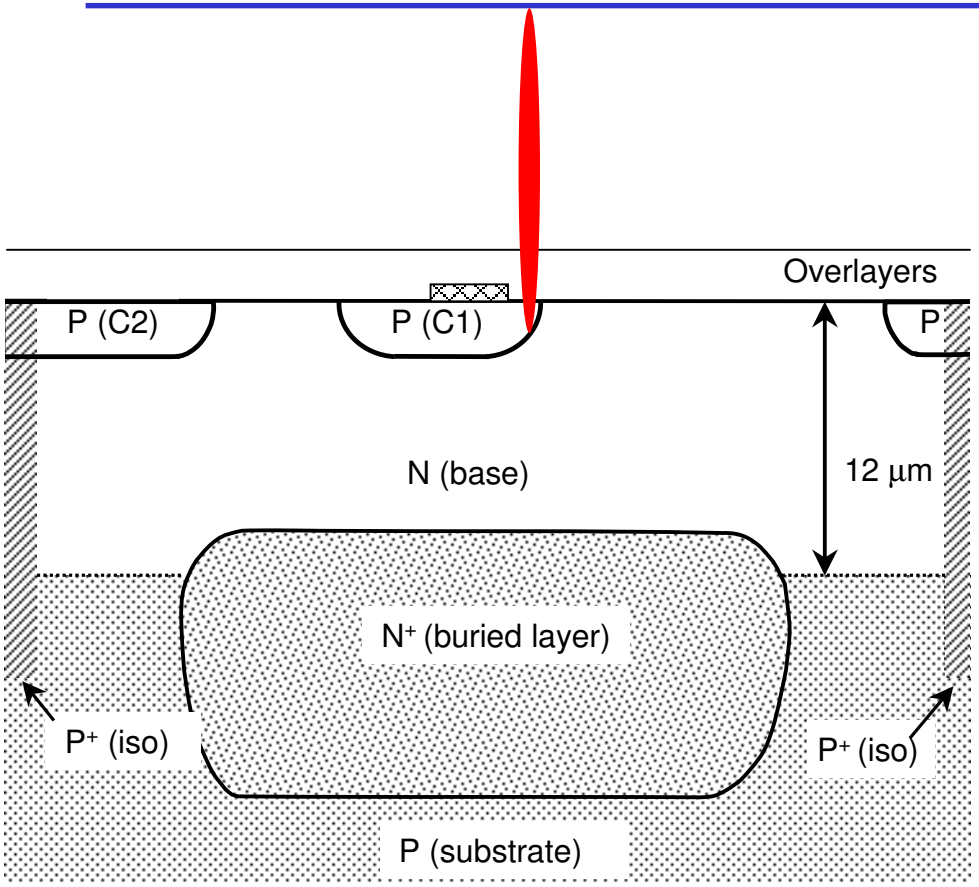
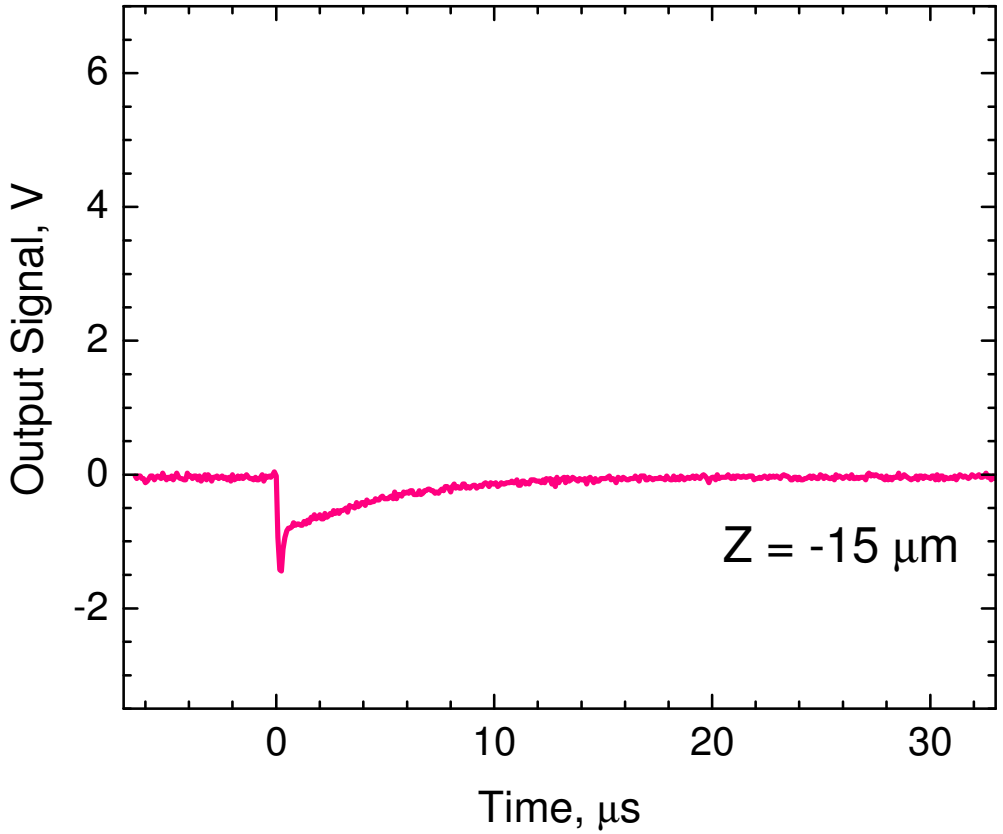




"Z" Dependence: LM124 Q20 TPA: C1-epi Junction

(Inverting Configuration; gain of 20)





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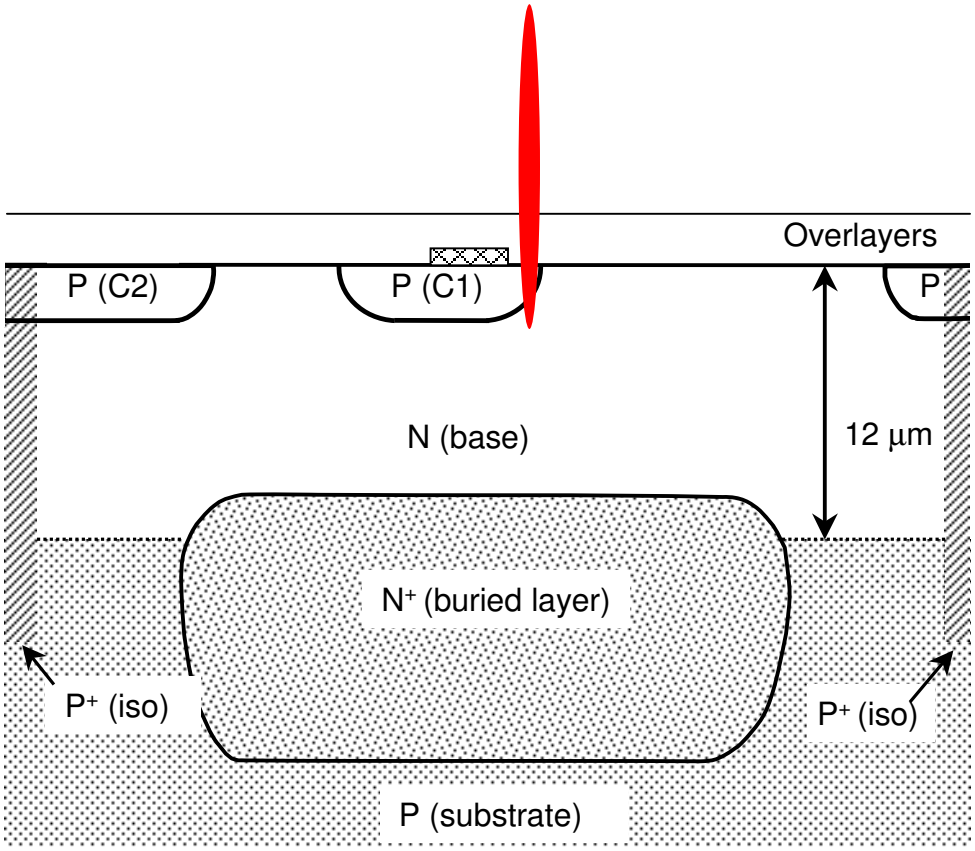

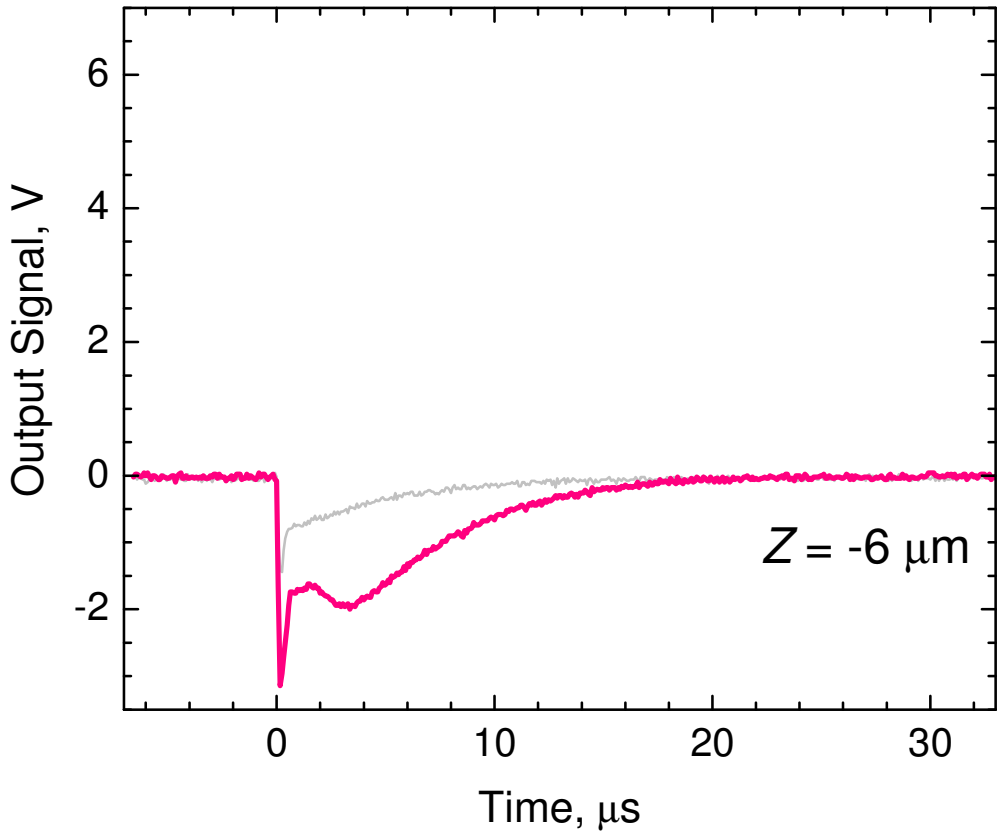

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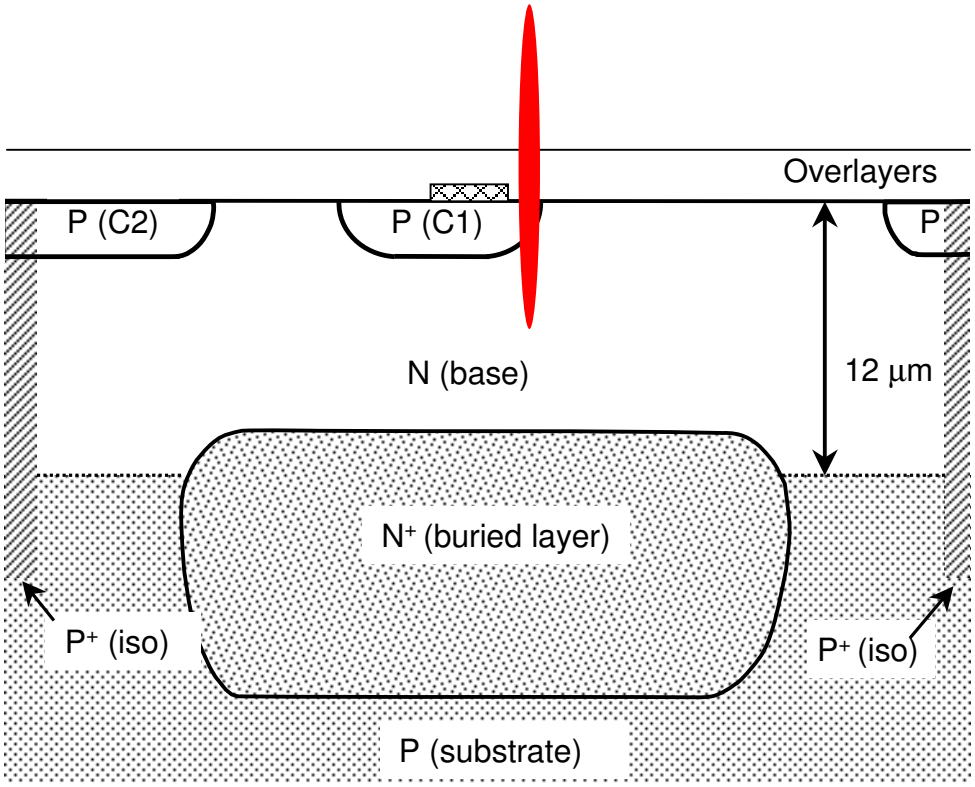

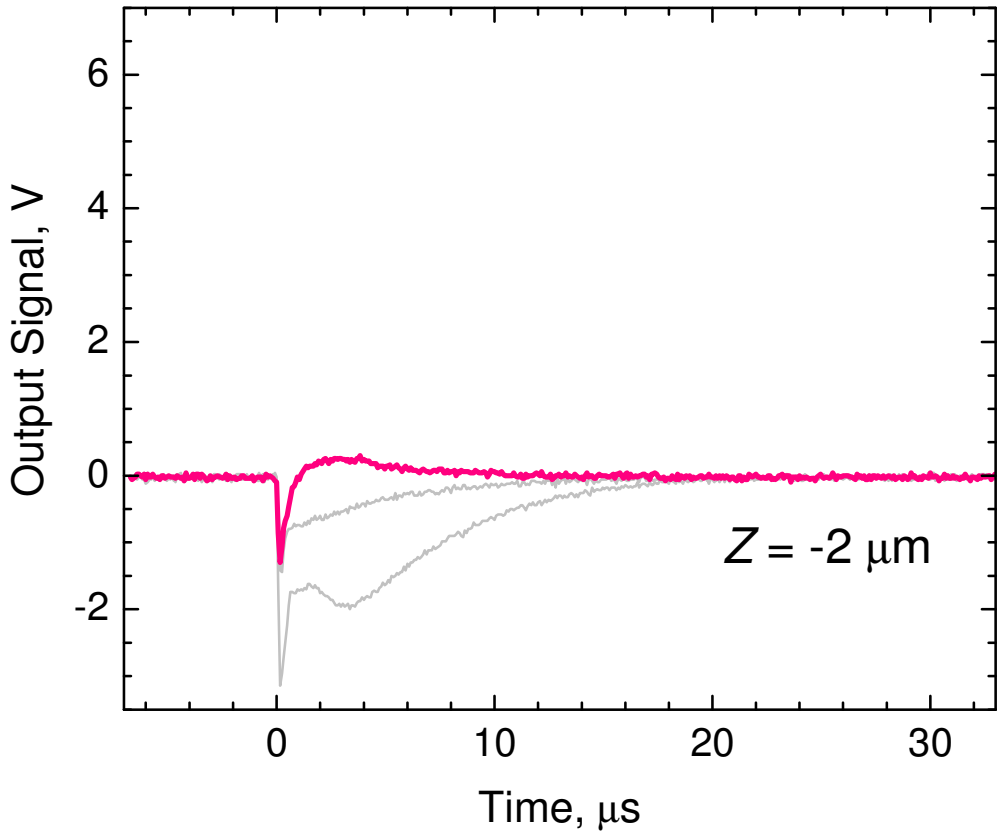

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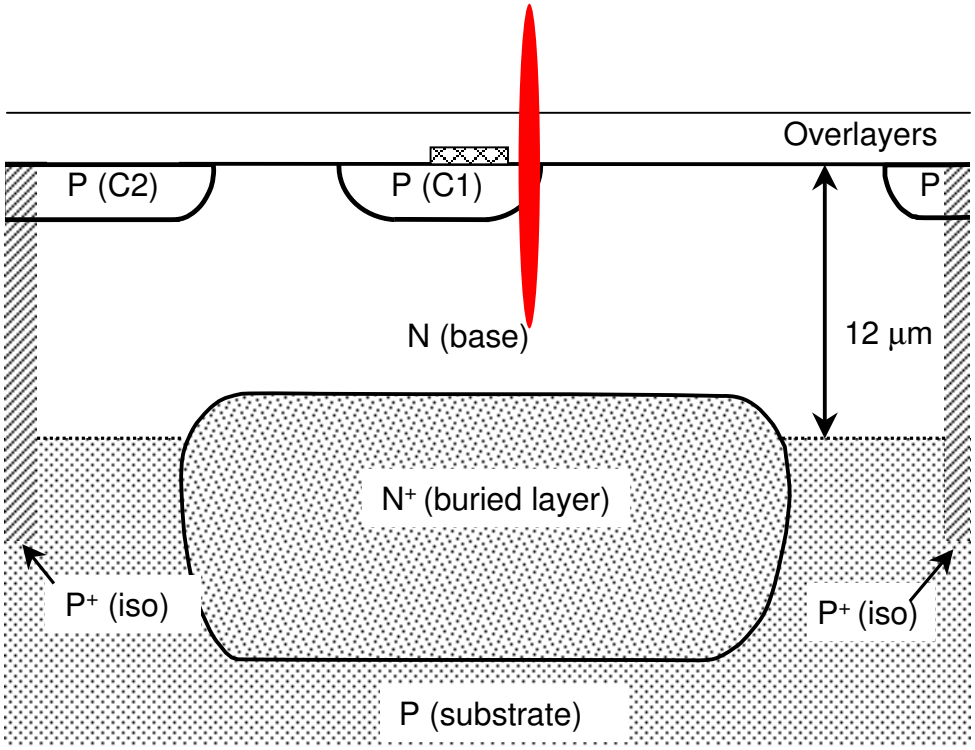

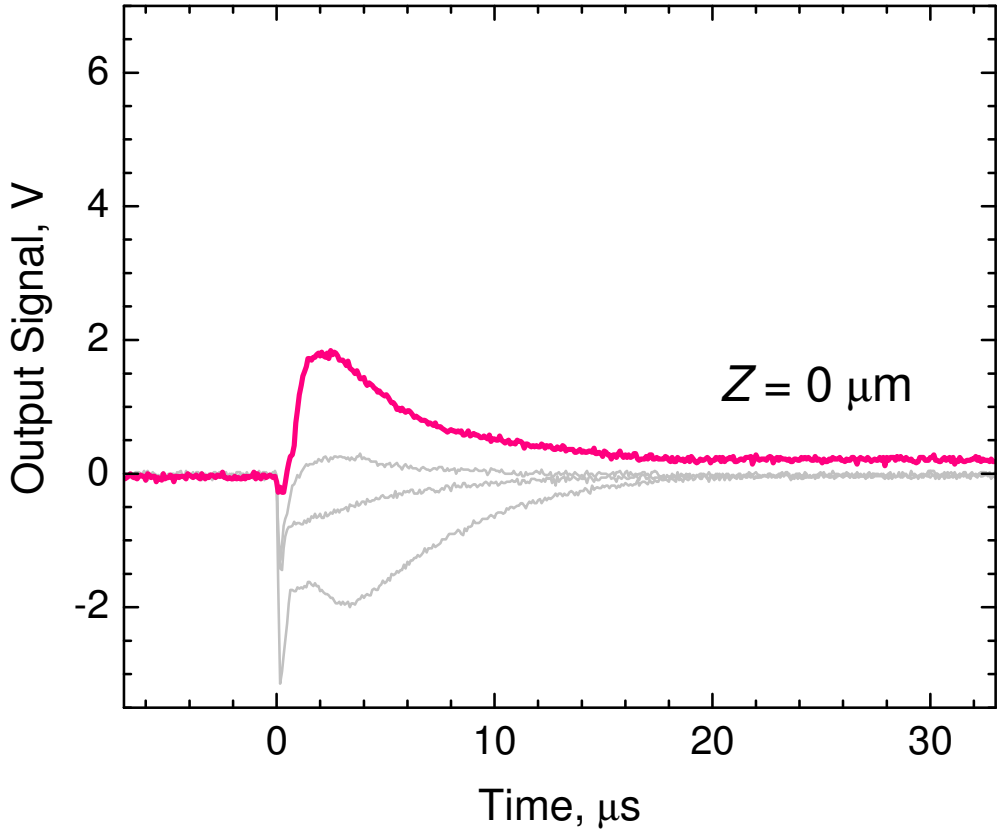

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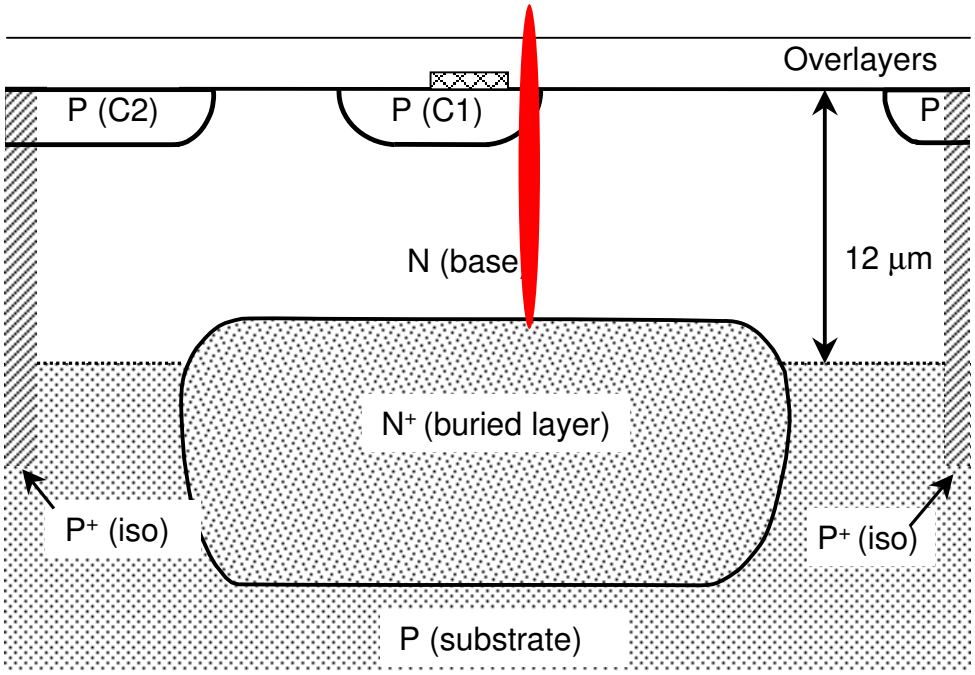

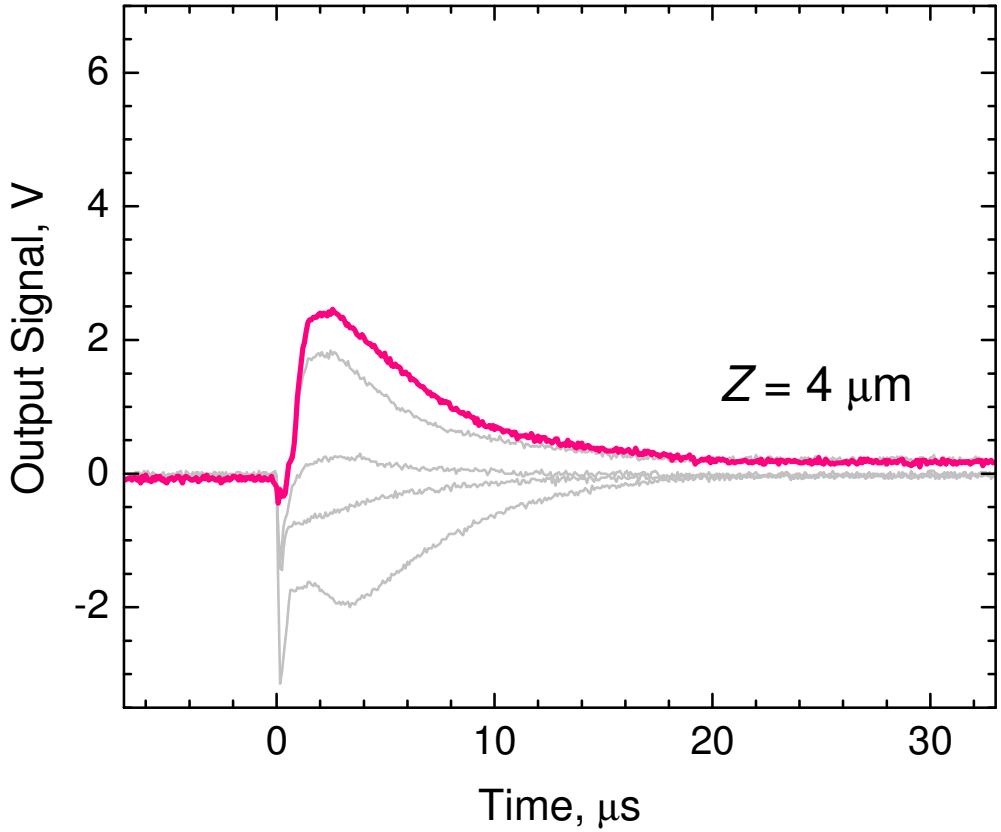

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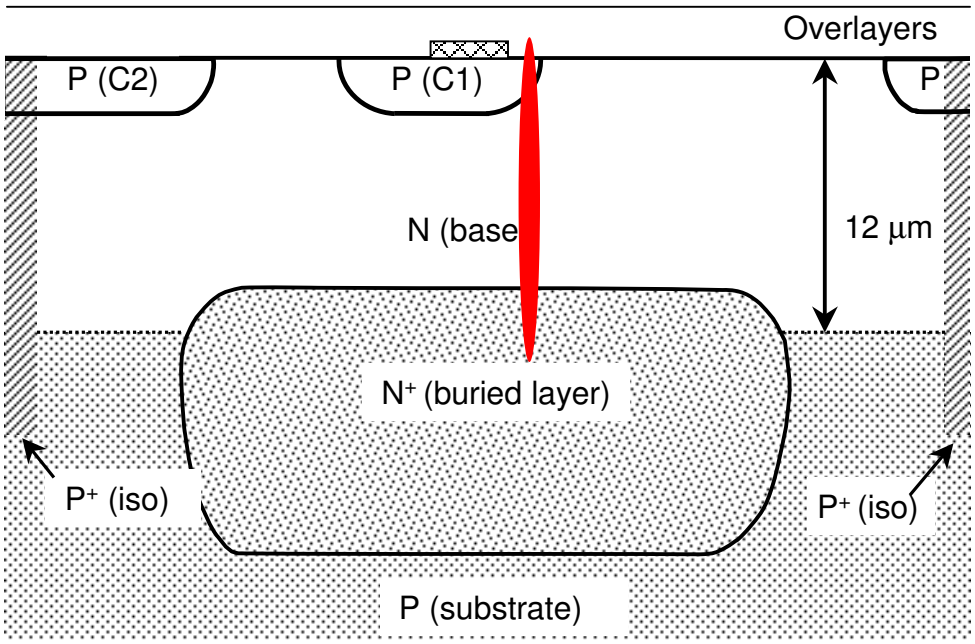

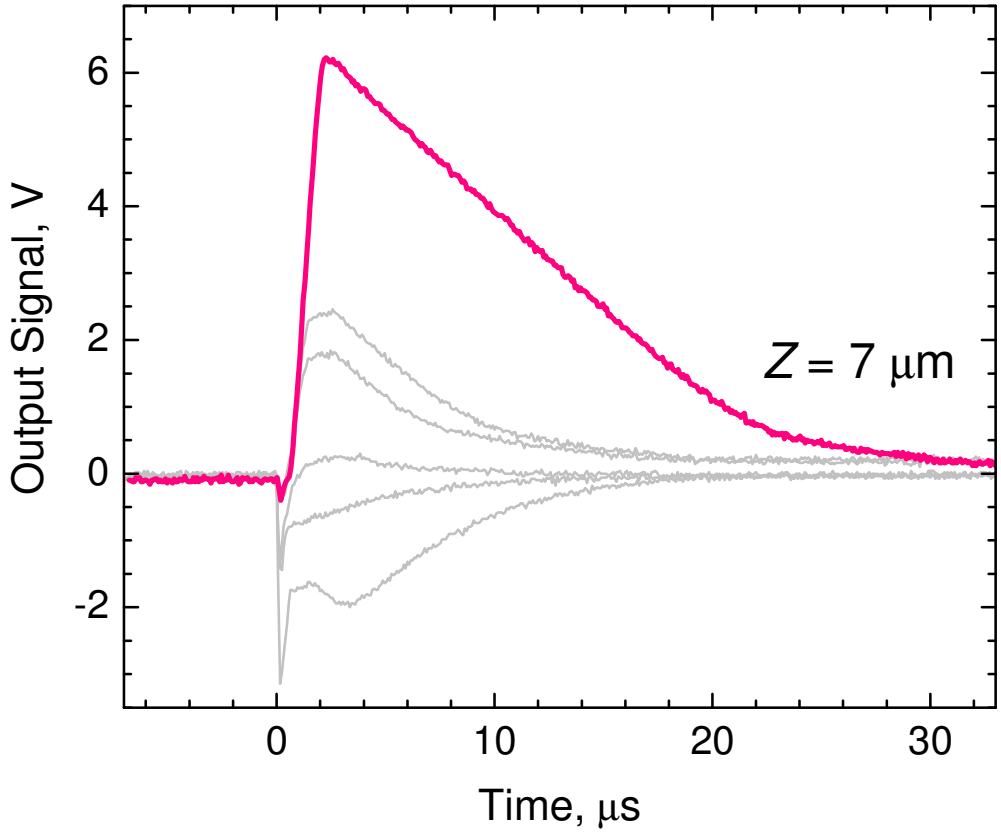

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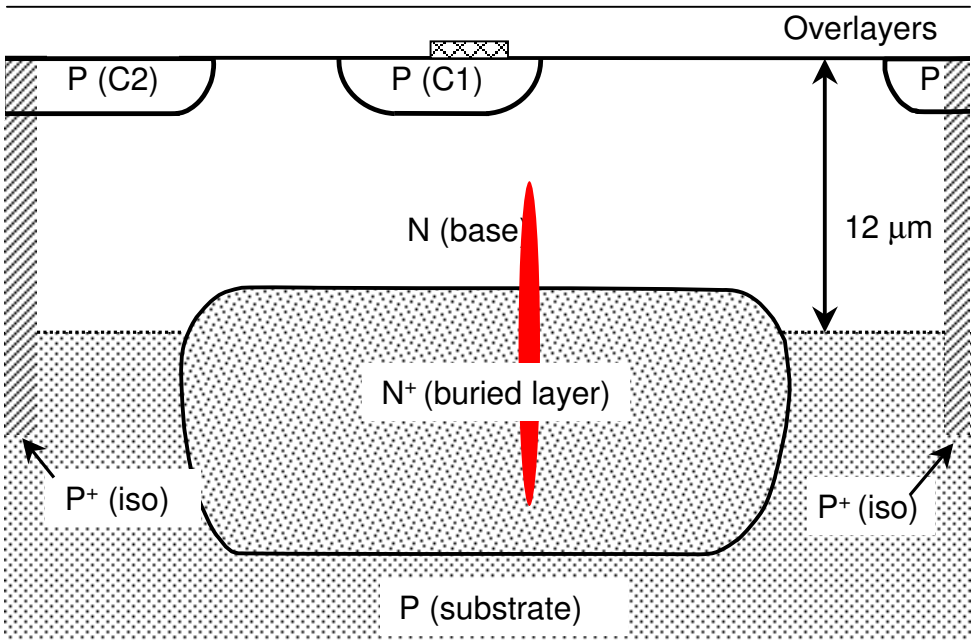

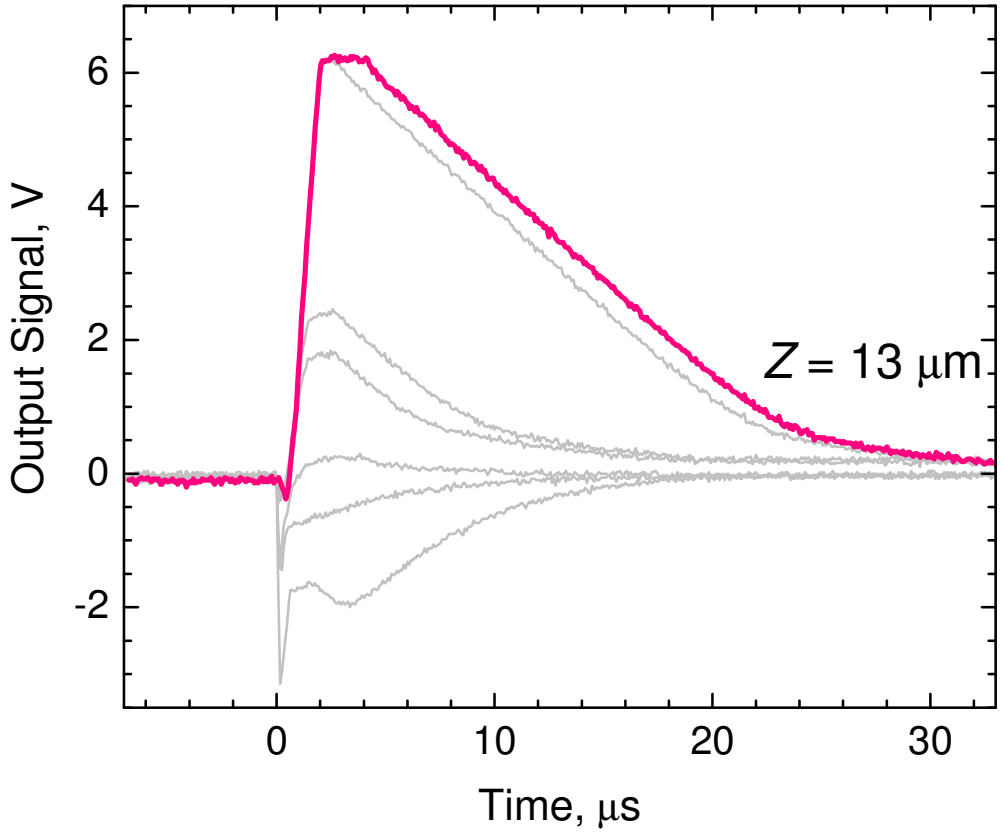

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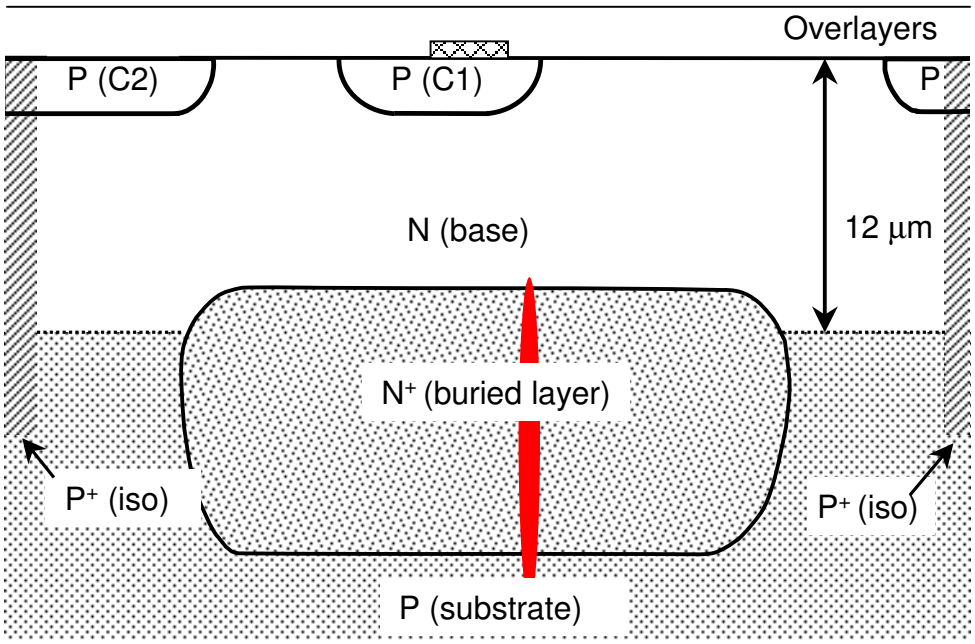

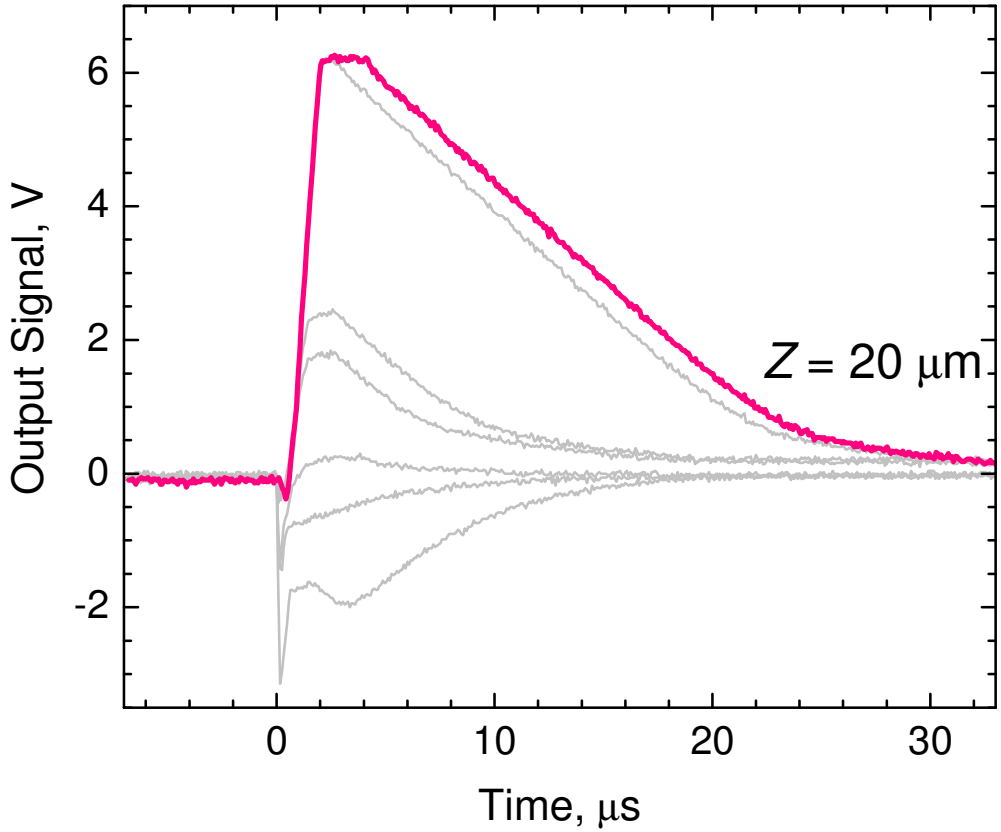

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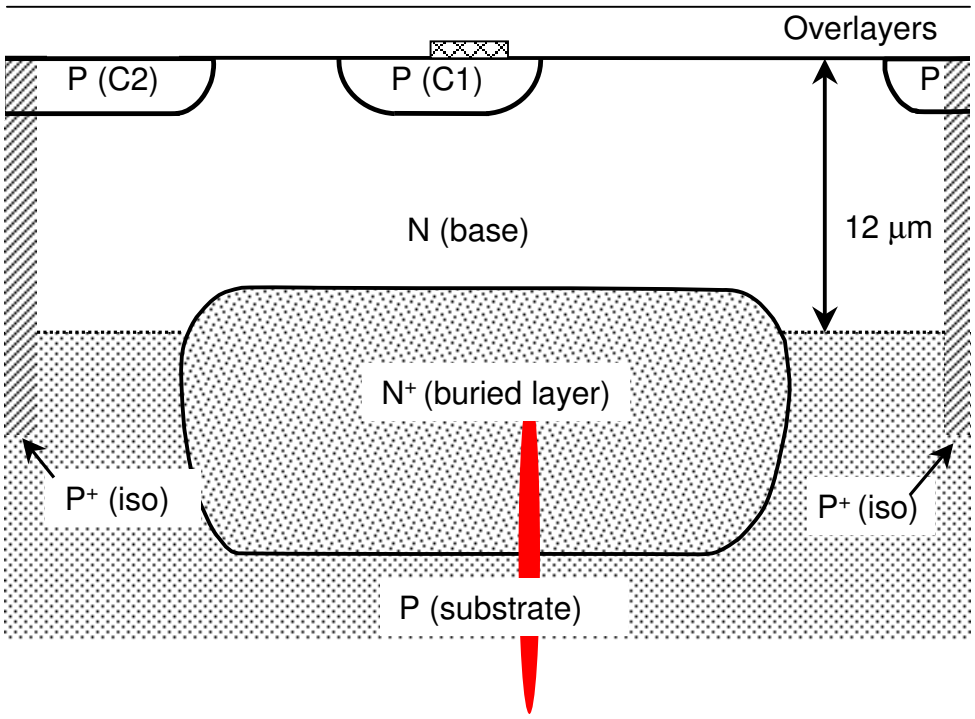

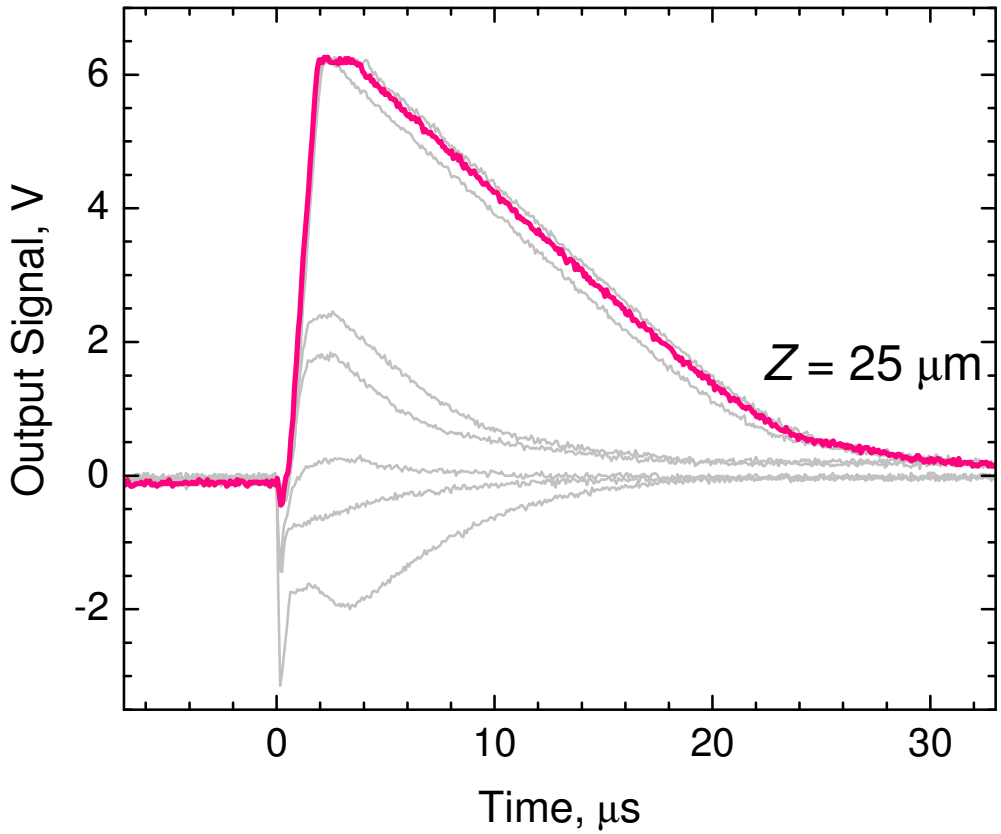

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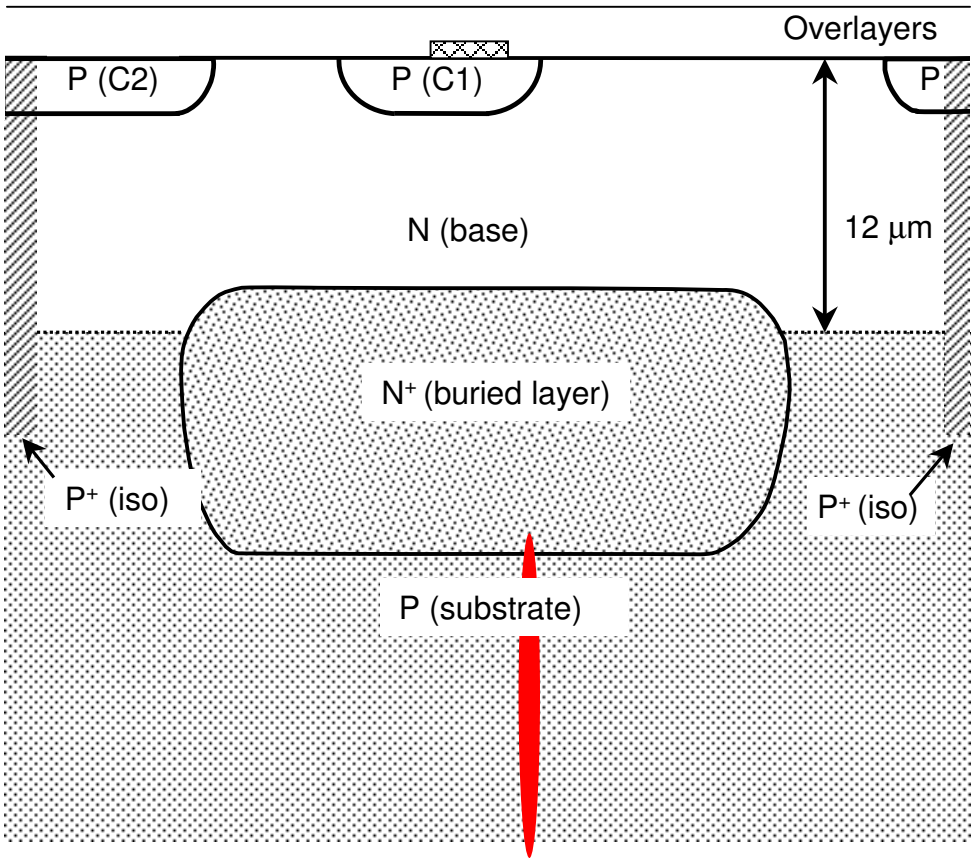

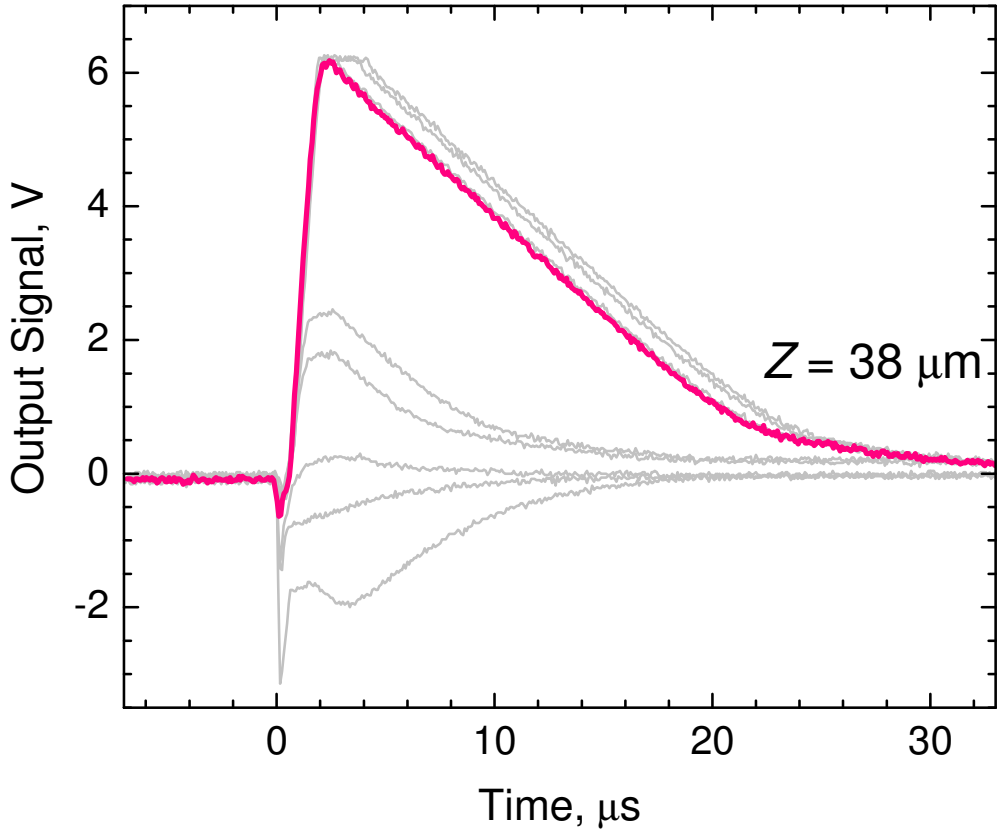

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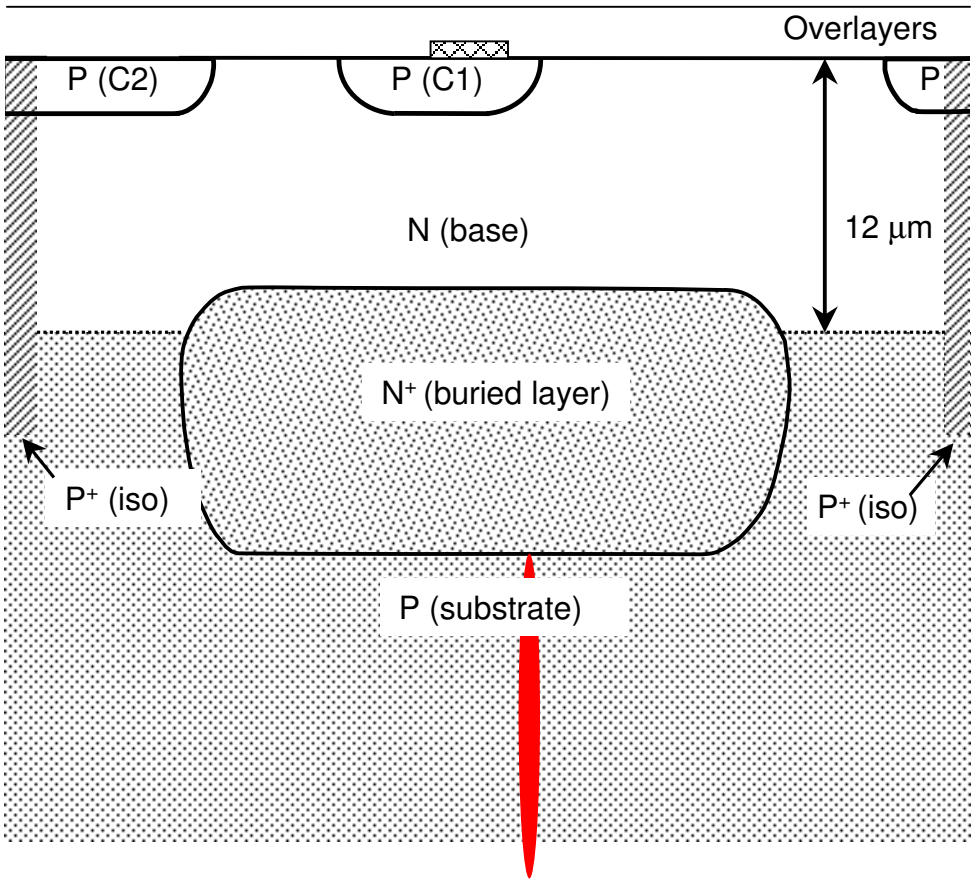

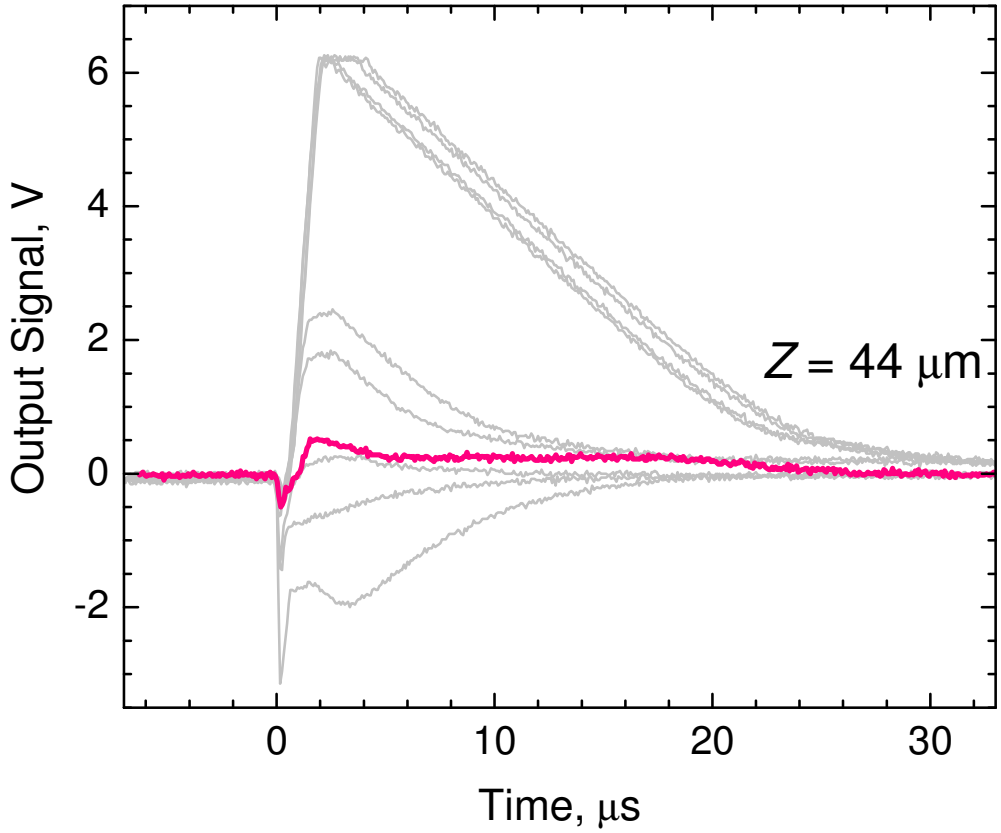

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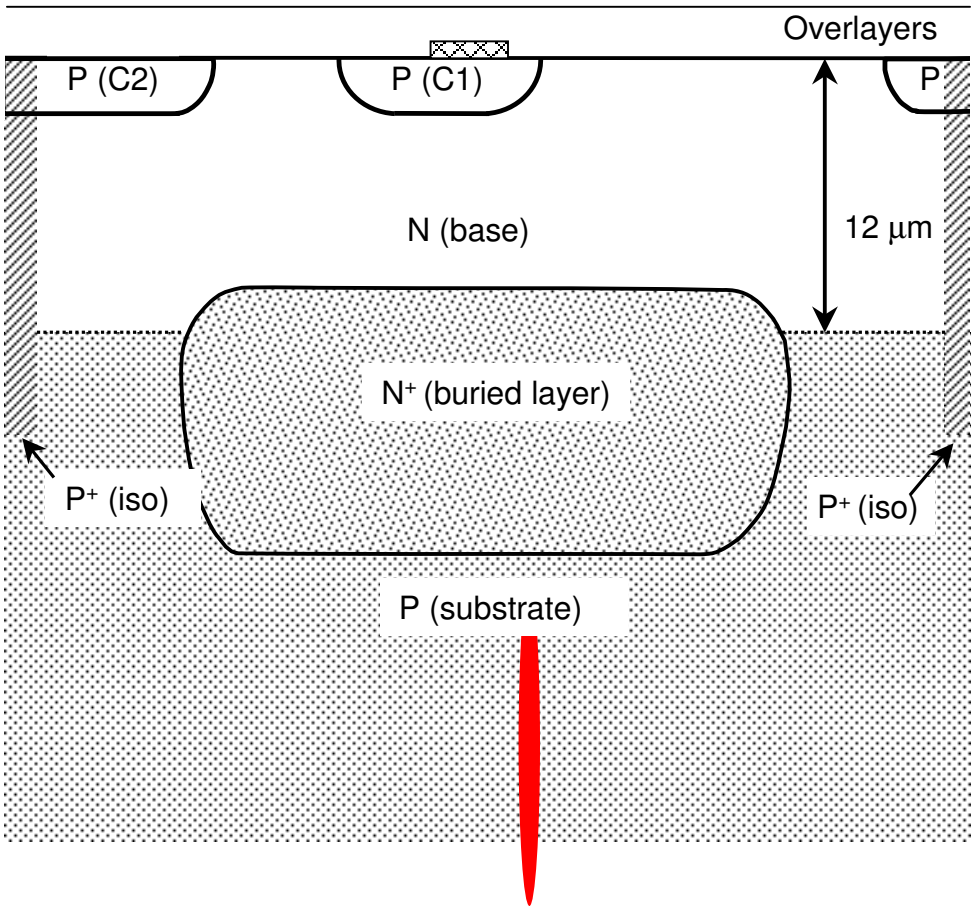

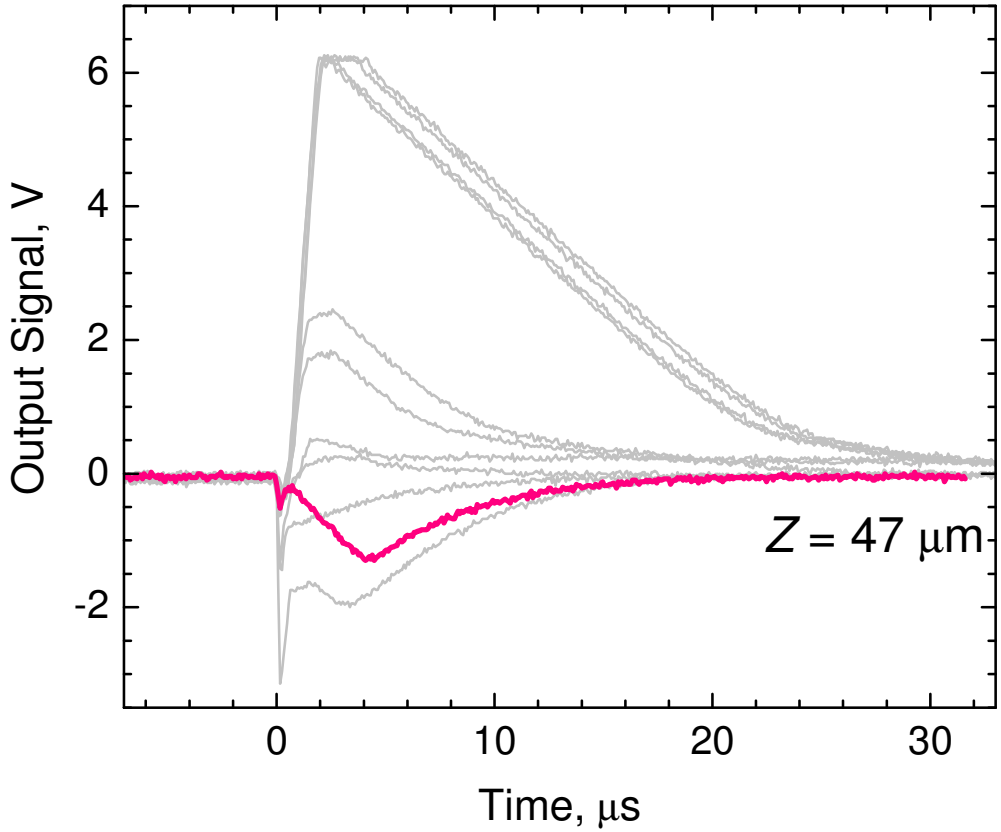

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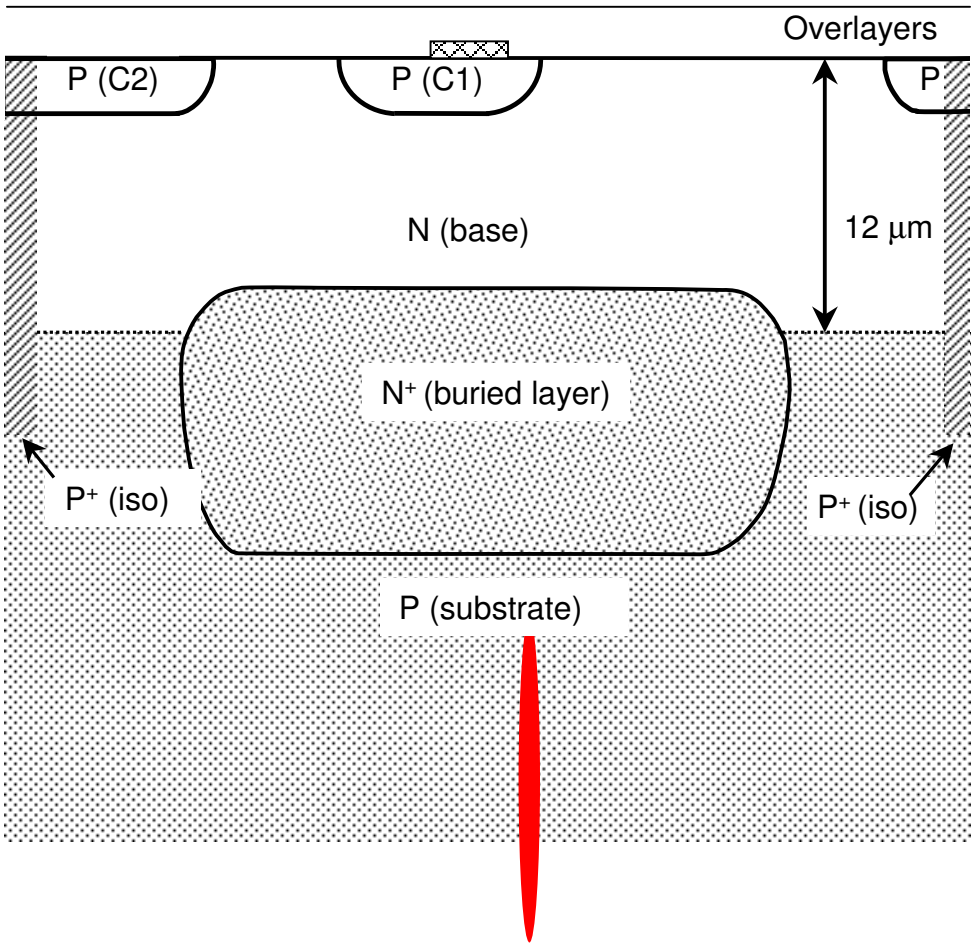

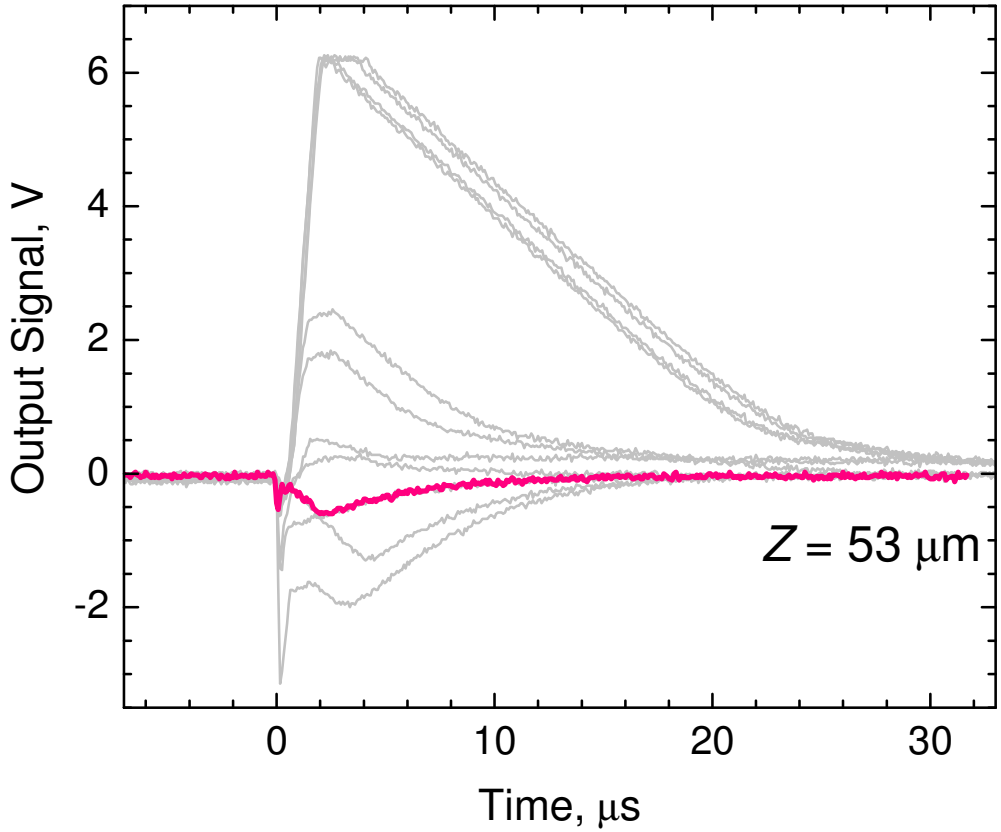

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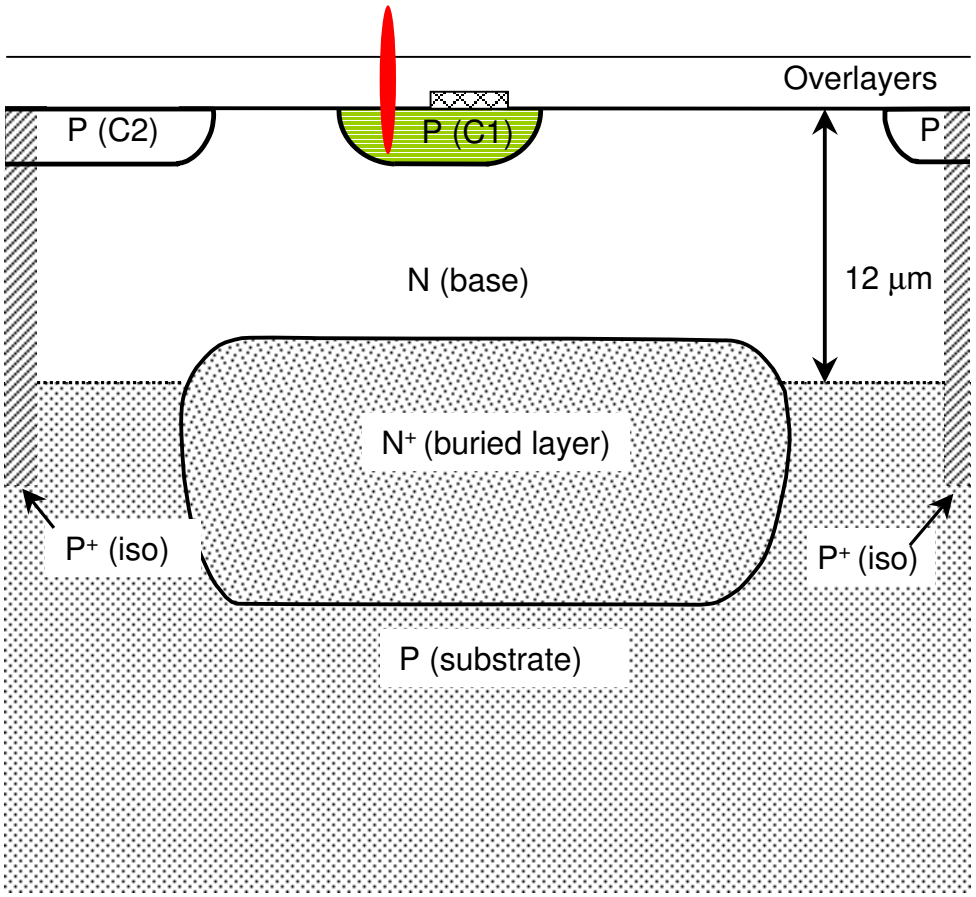
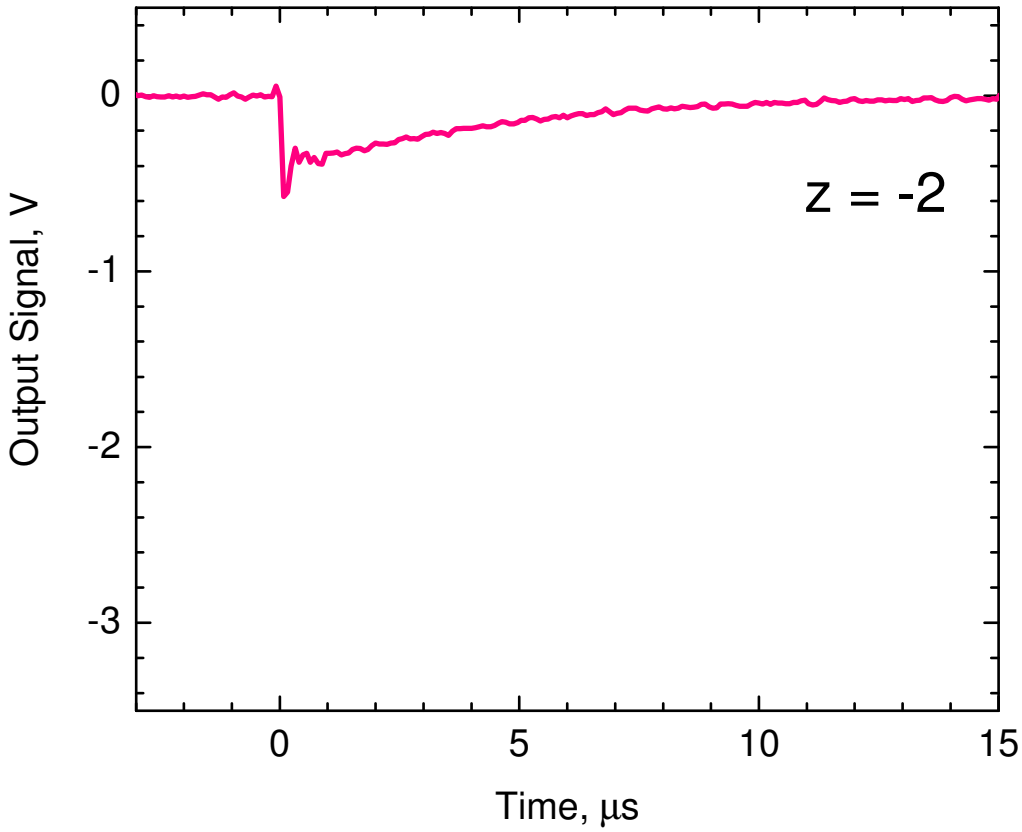
Low Power Measurements





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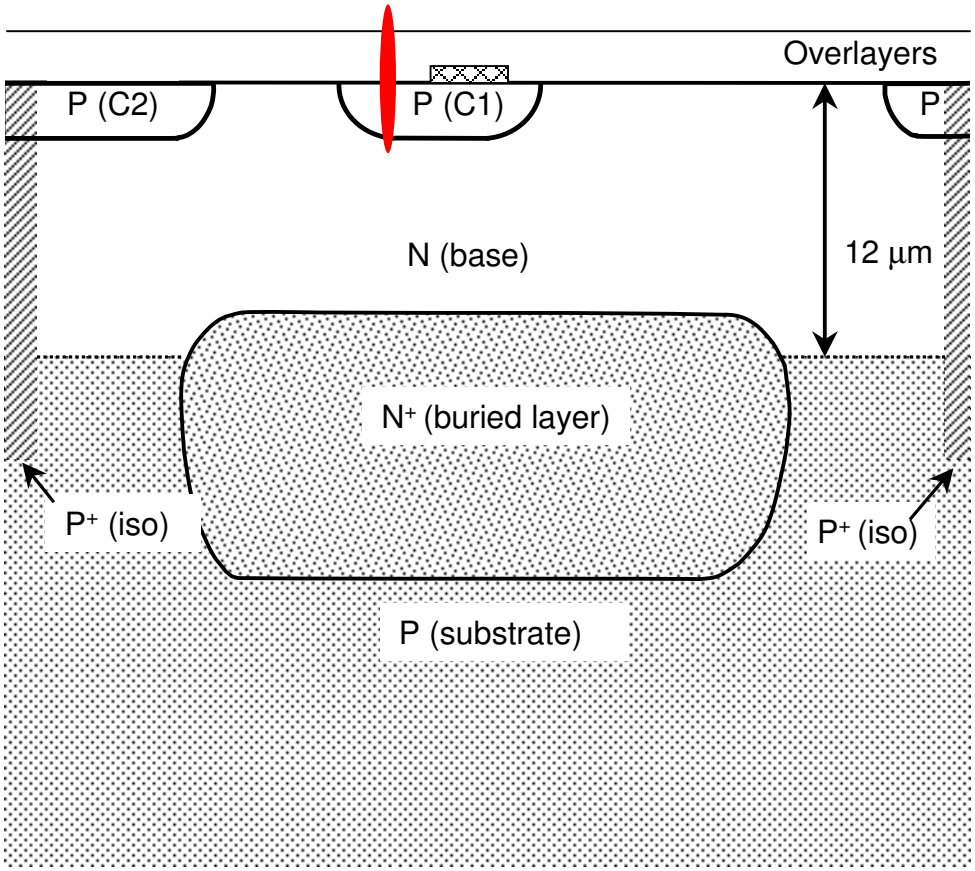

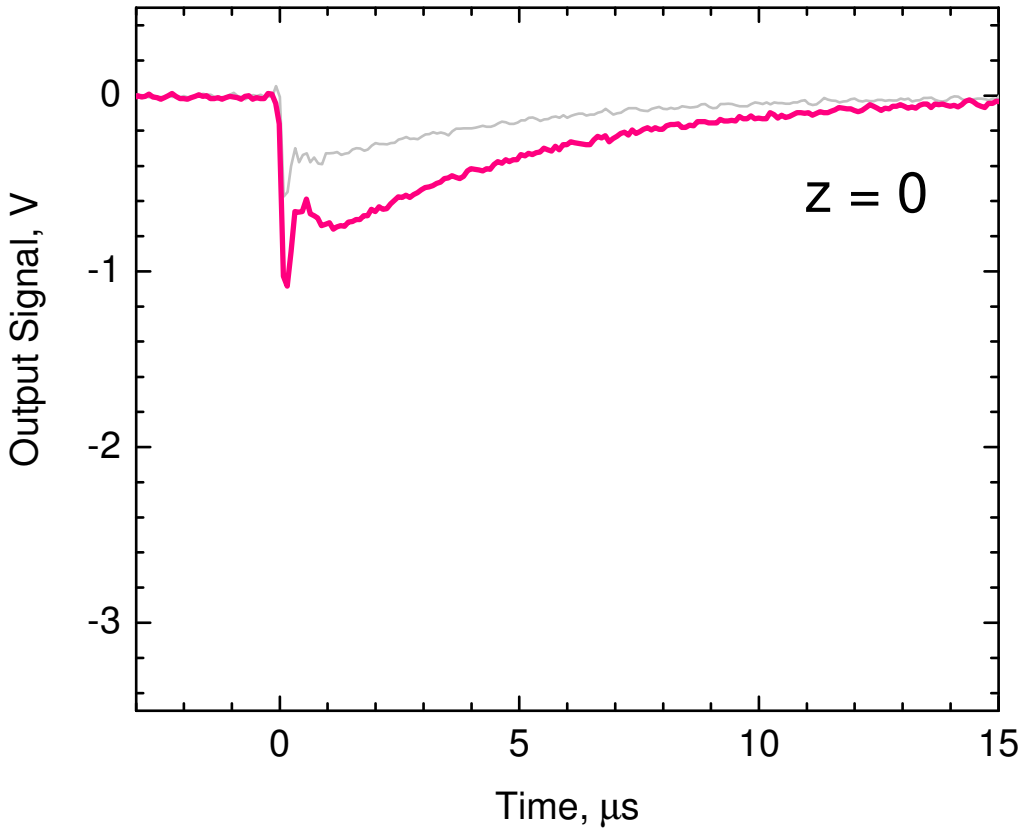

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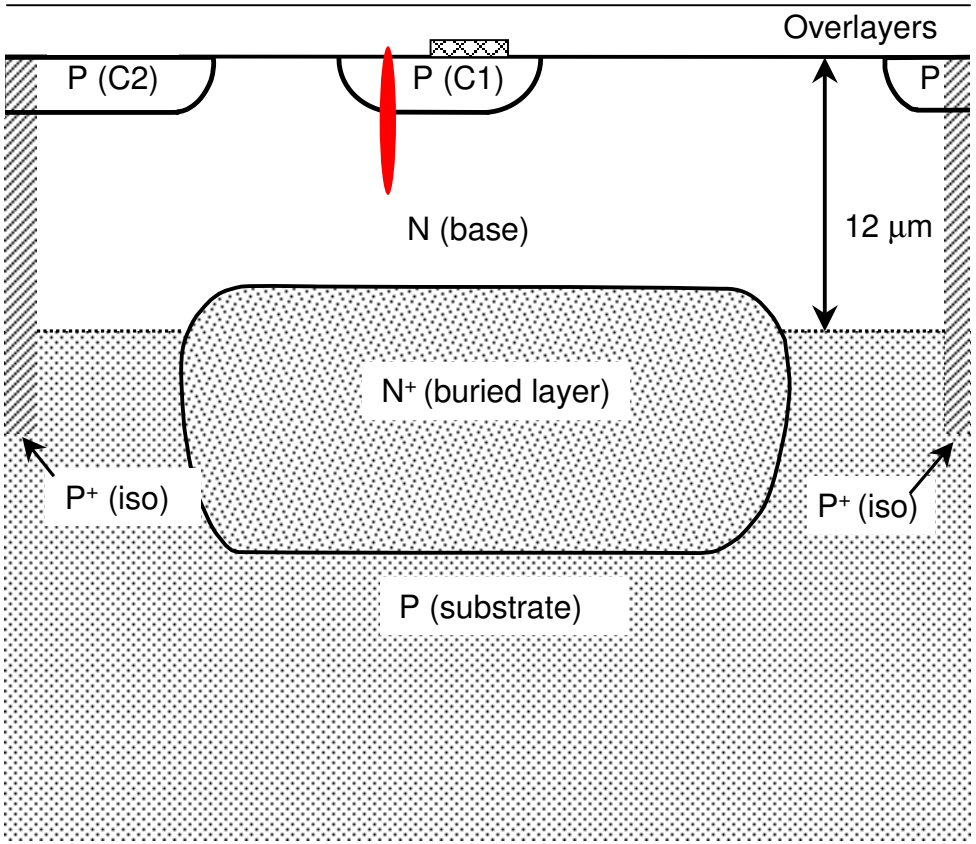

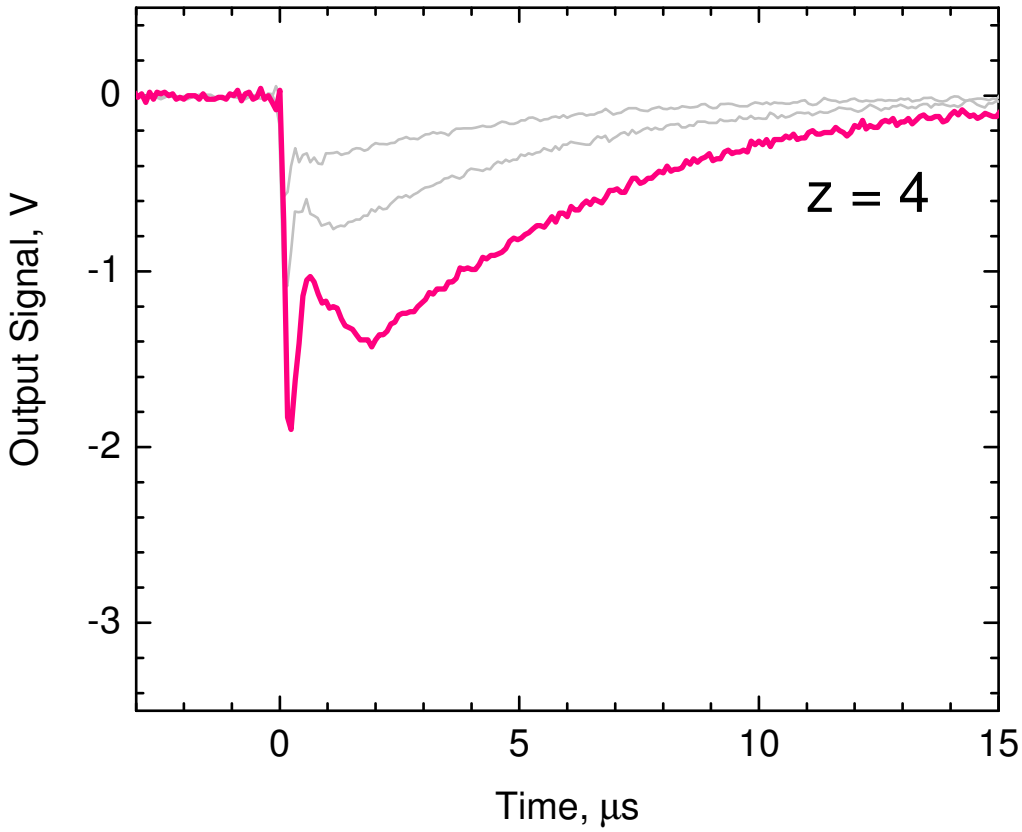

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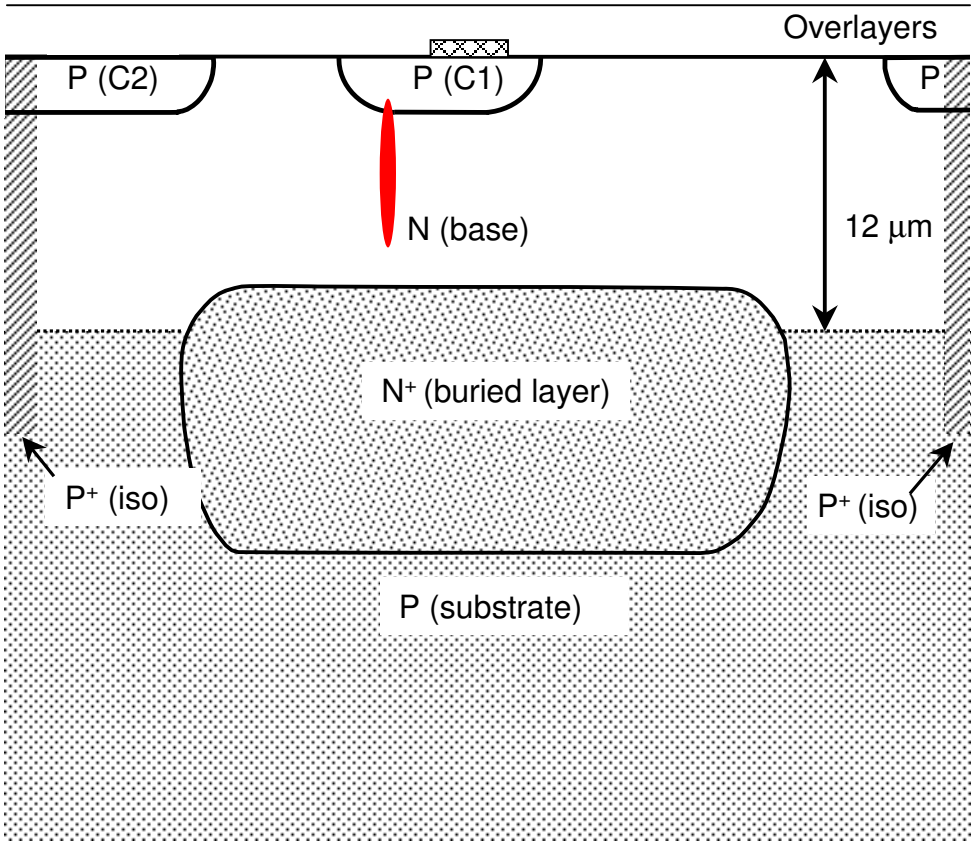

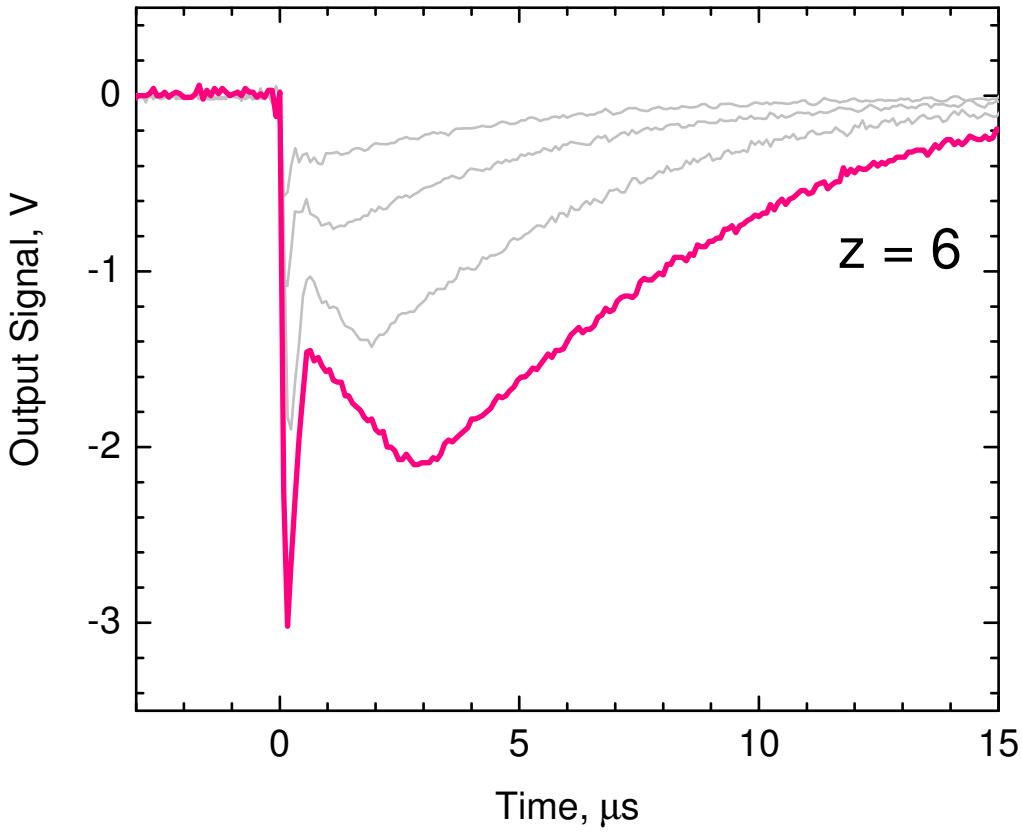

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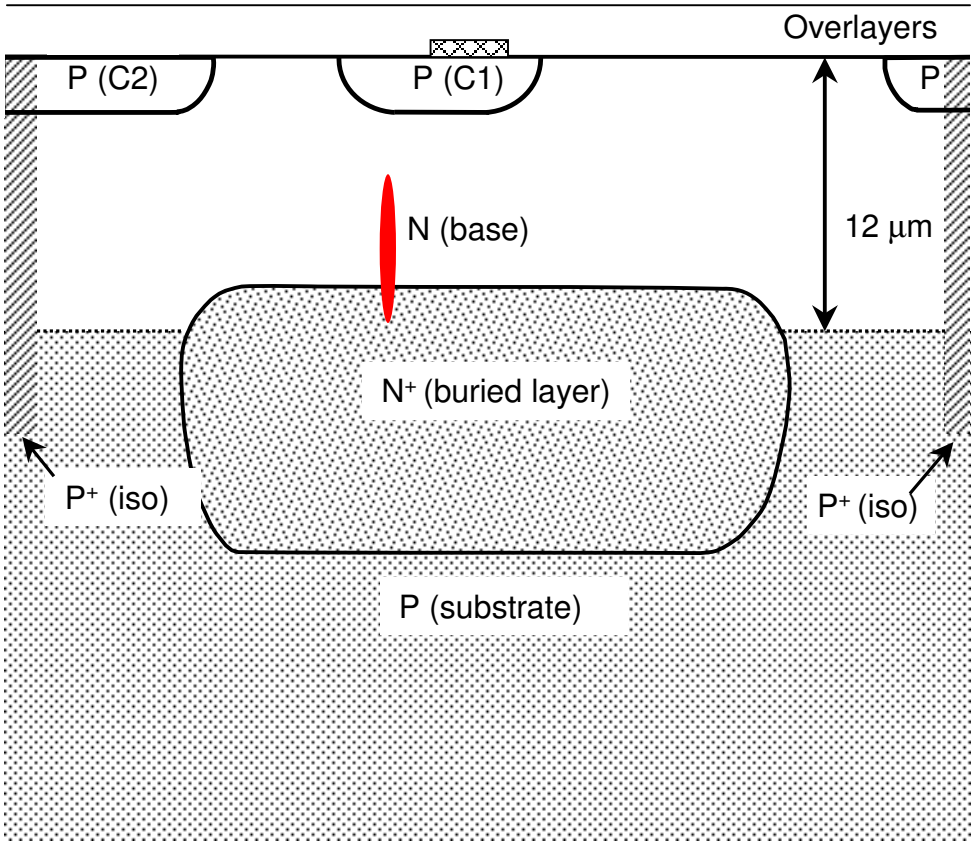

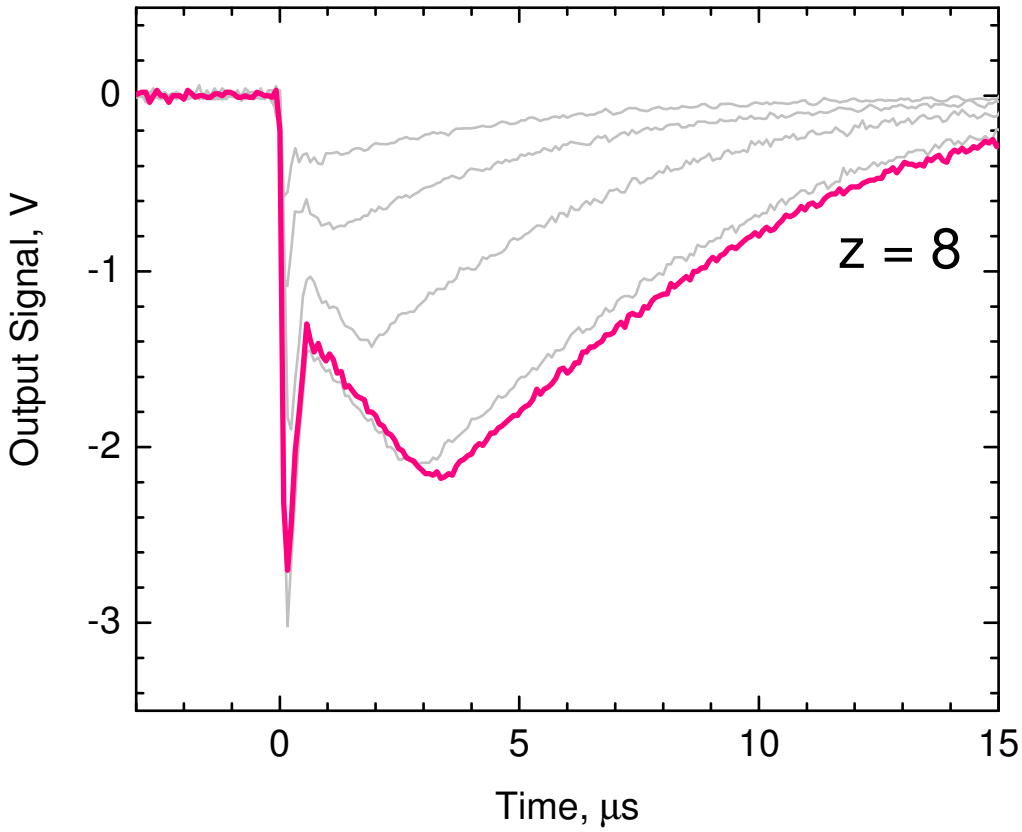

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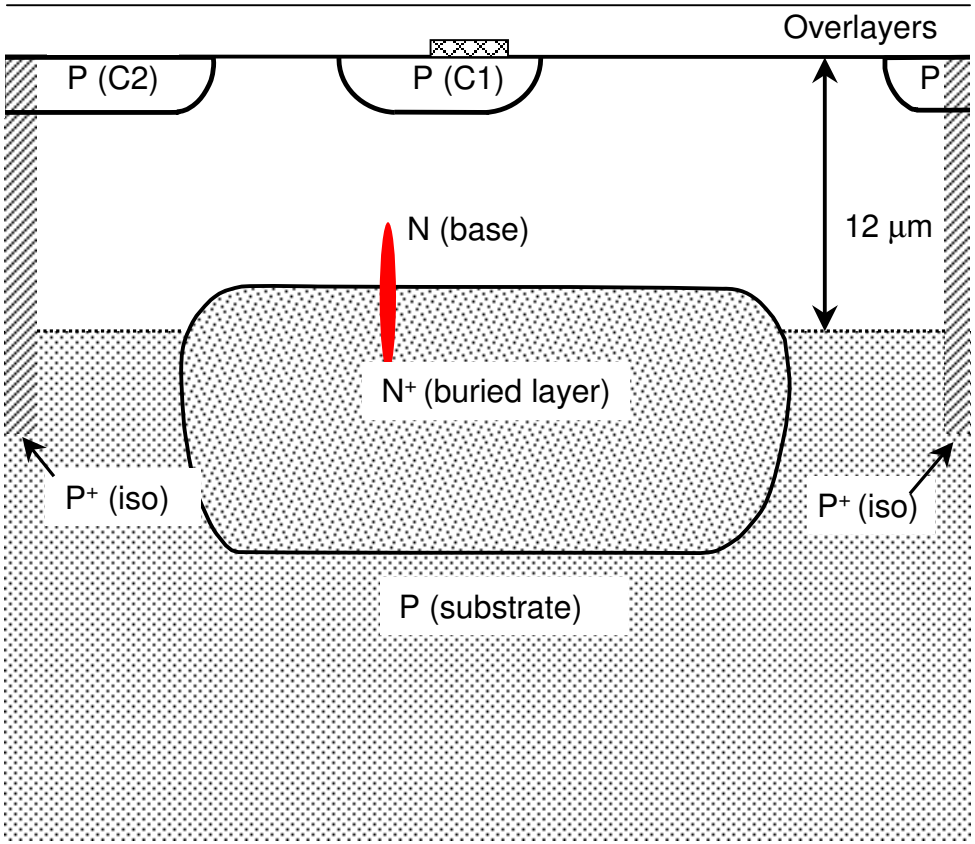

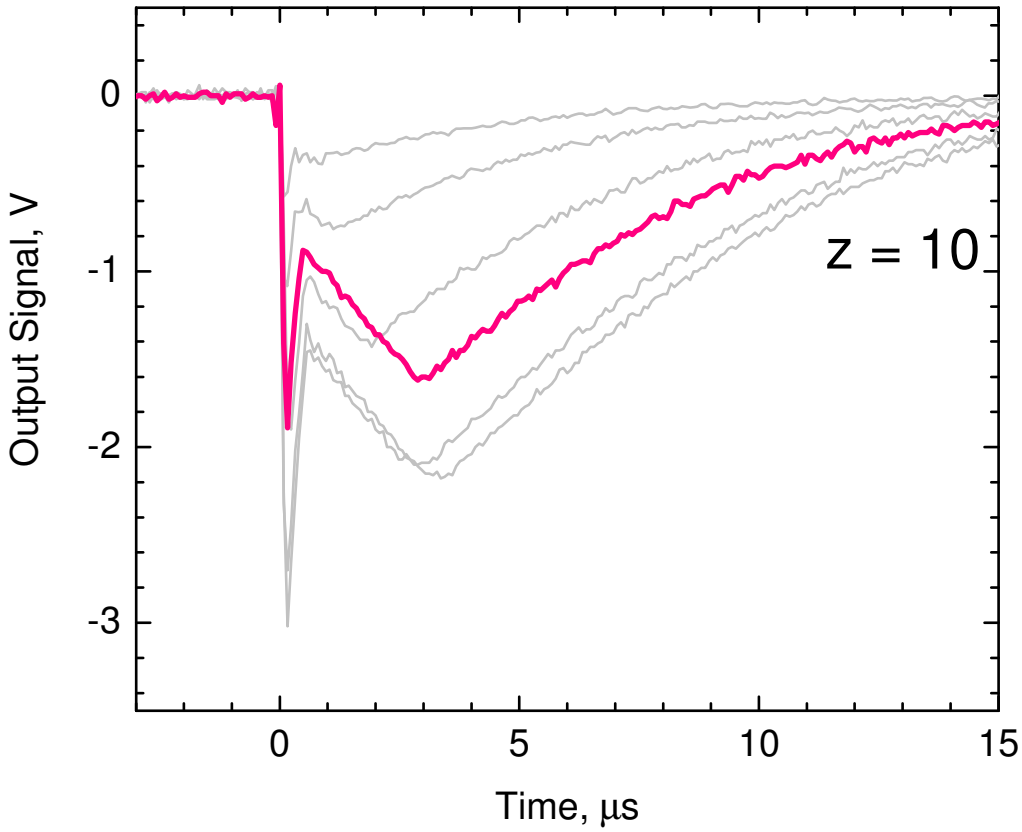

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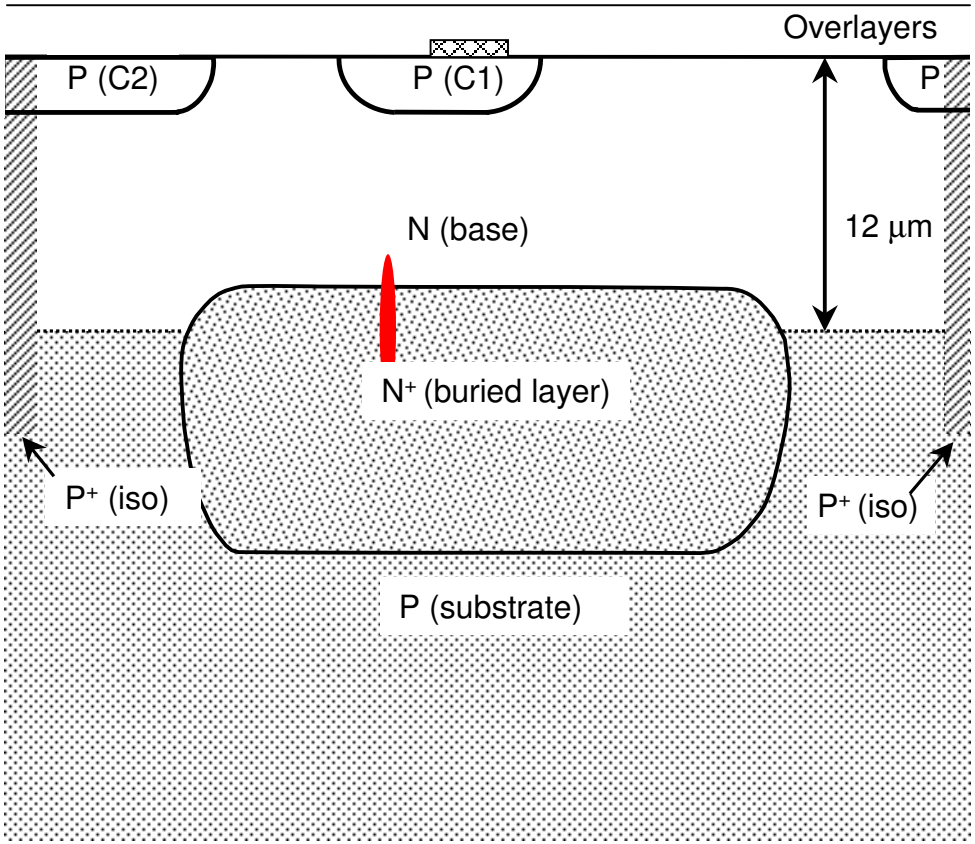
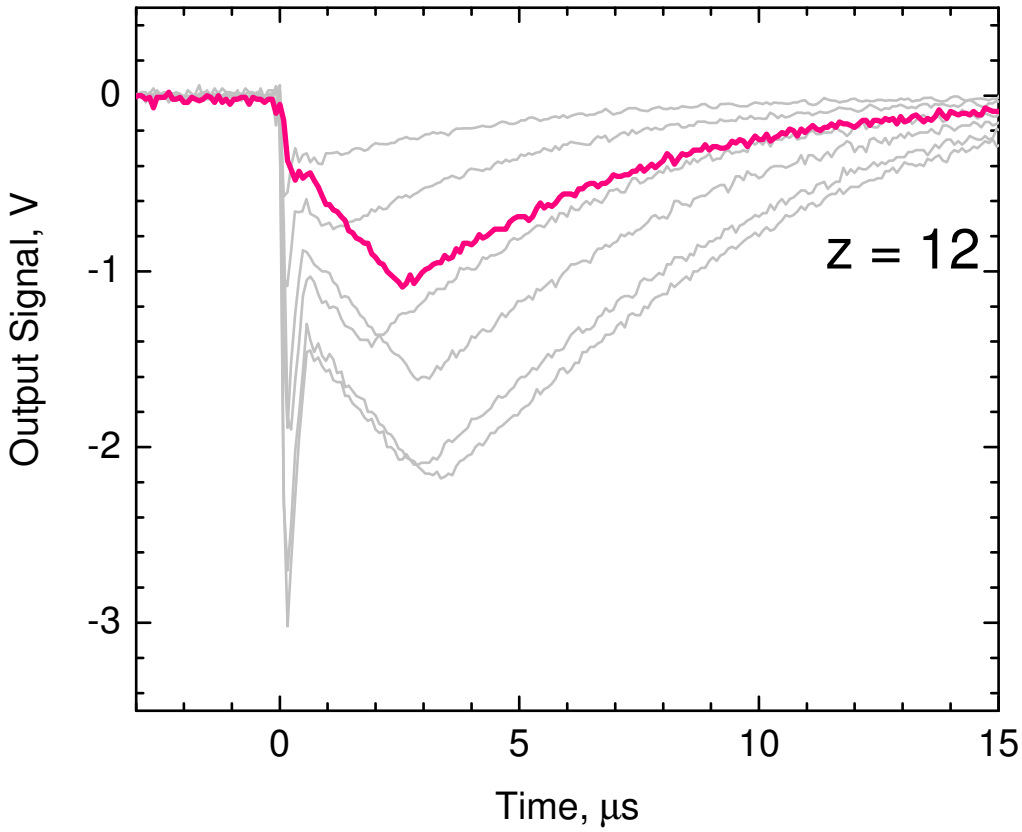
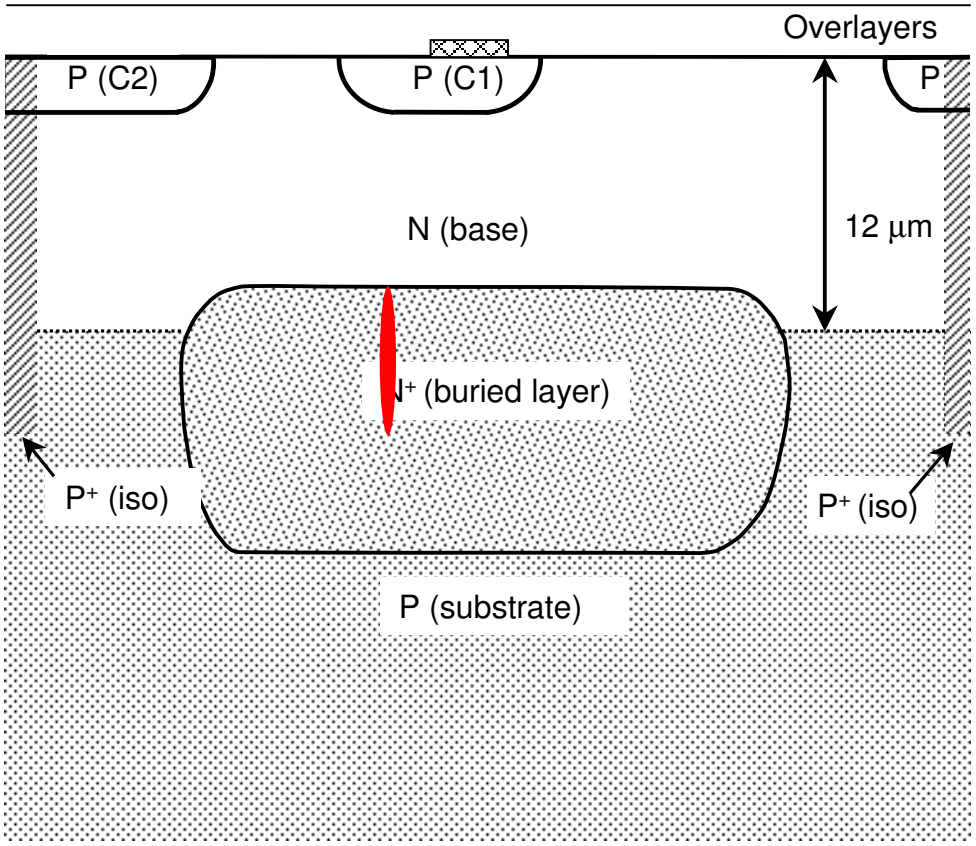
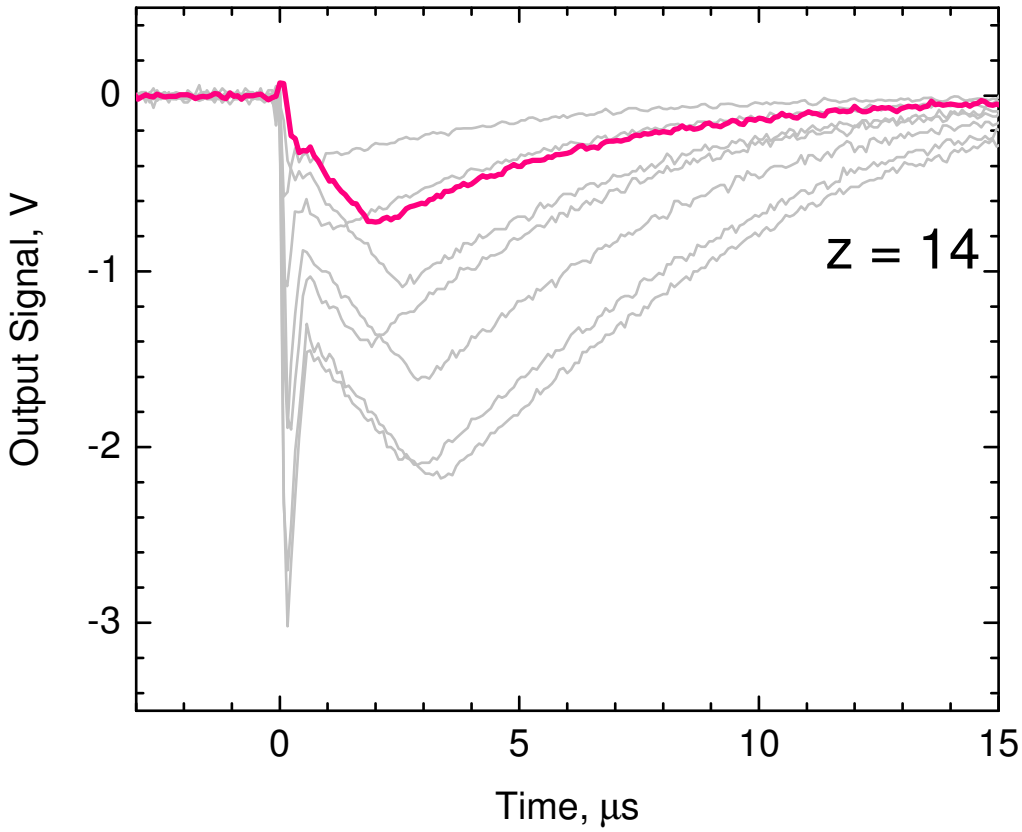




"Z" Dependence: LM124 Q20 TPA: Low Power

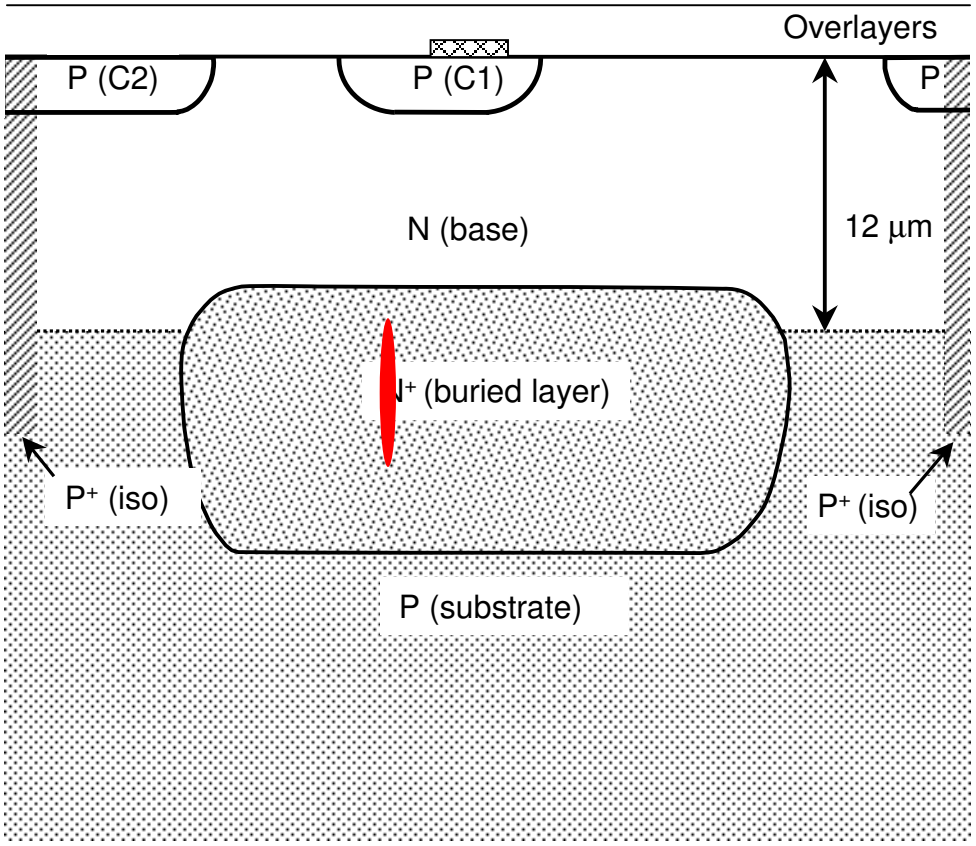
(Inverting Configuration; gain of 20)

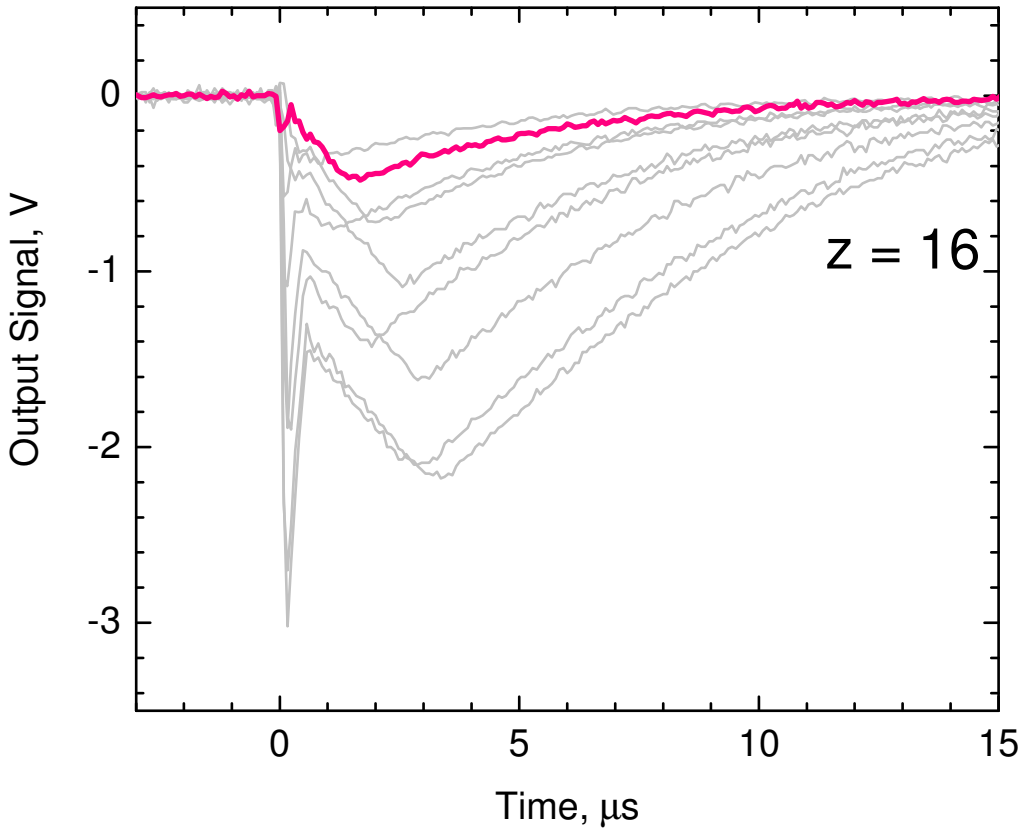




"Z" Dependence: LM124 Q20 TPA: Low Power

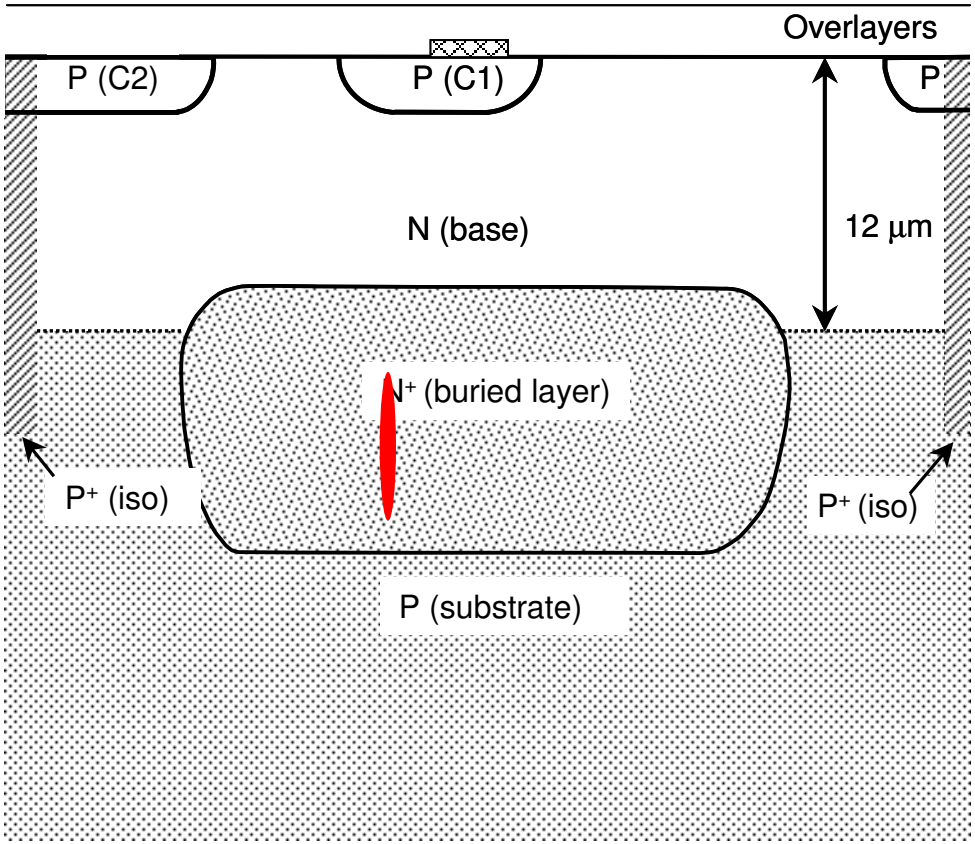
(Inverting Configuration; gain of 20)

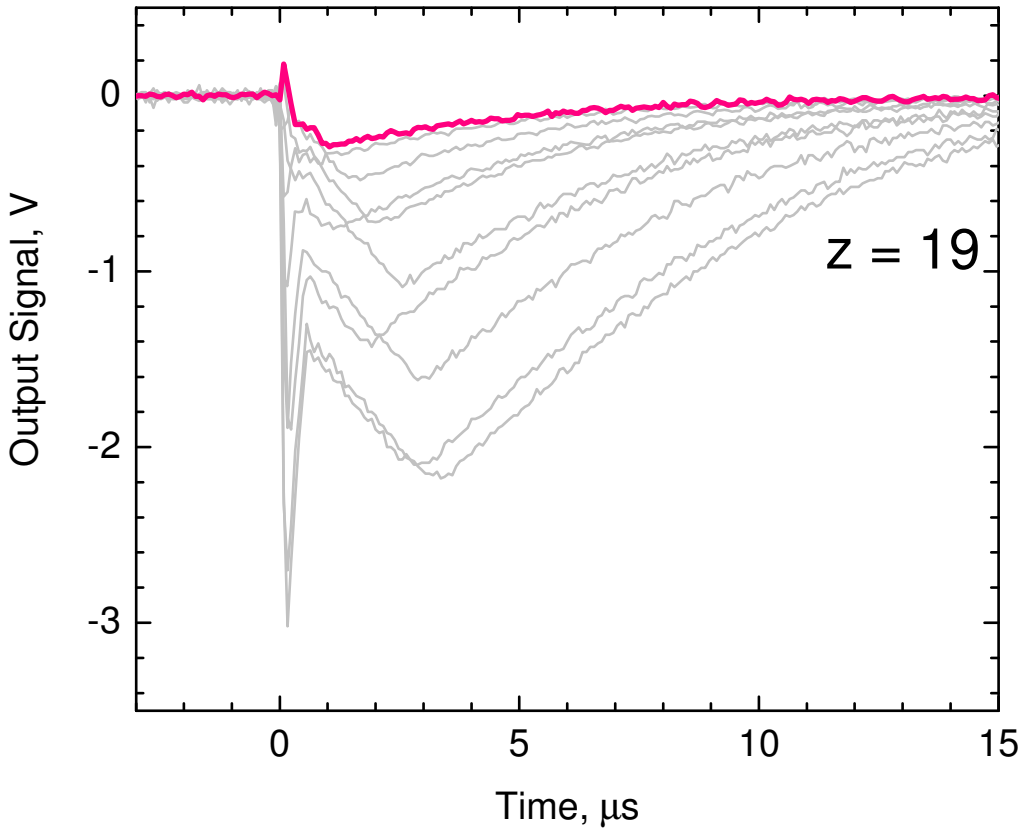




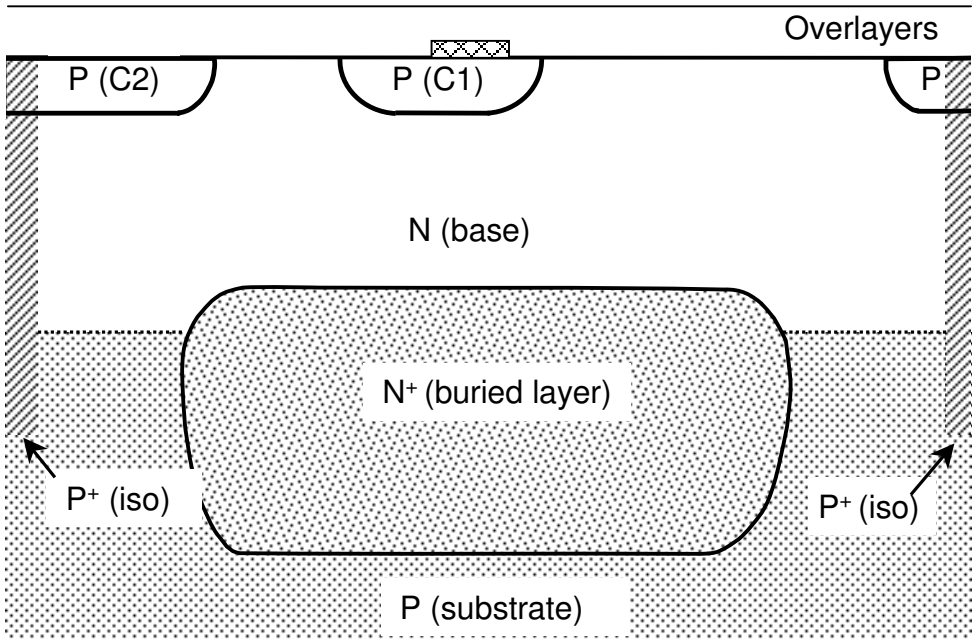
"Z" Dependence: LM124 Q20 TPA: Low Power

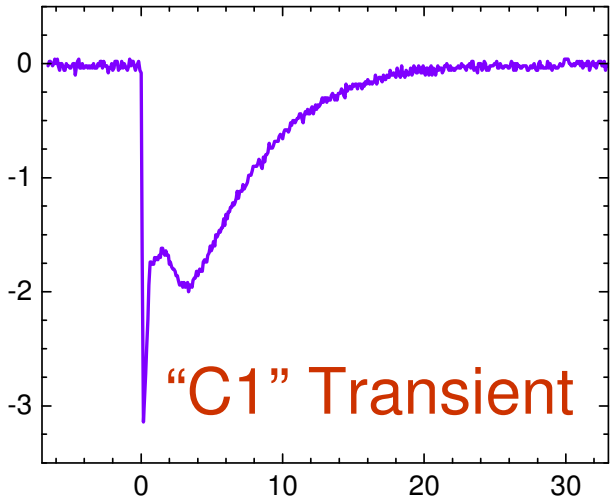
(Inverting Configuration; gain of 20)

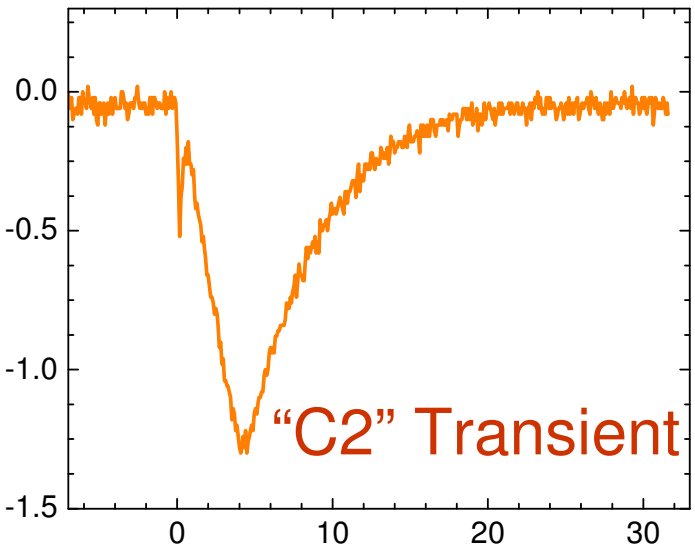


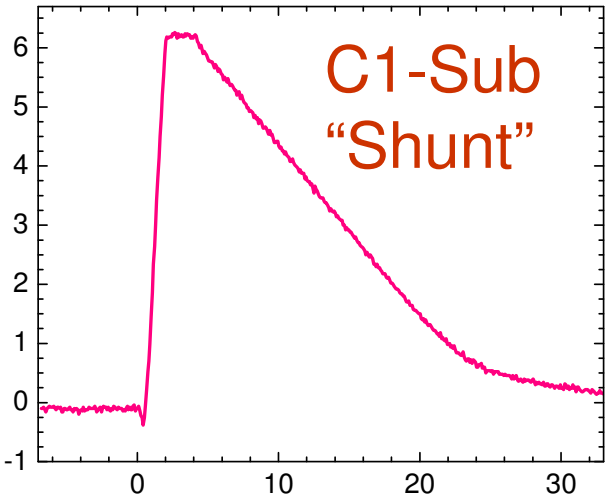


LM124 Q20 TPA SET: “Z” Dependence

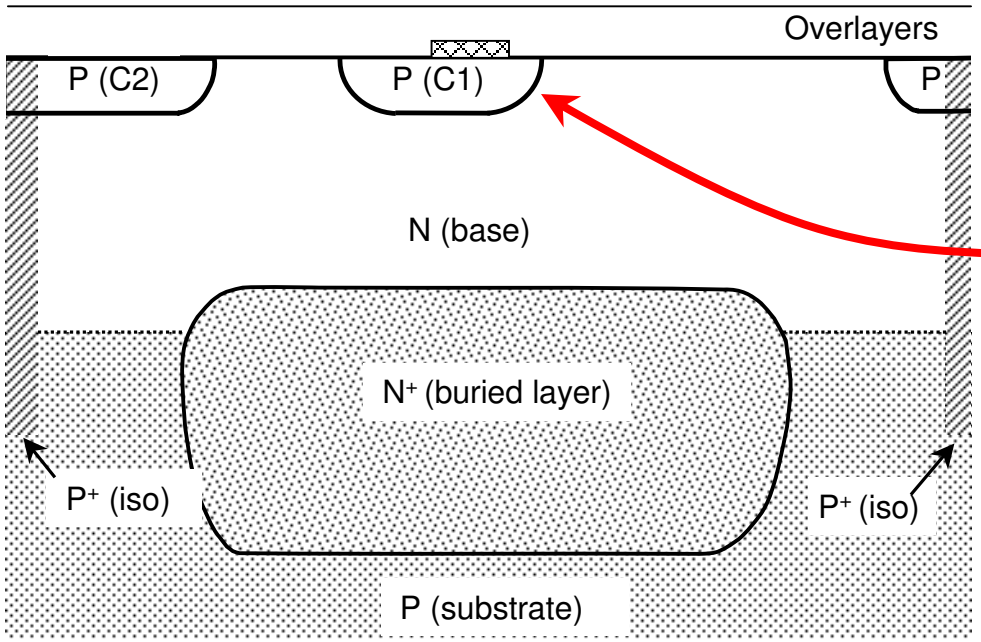


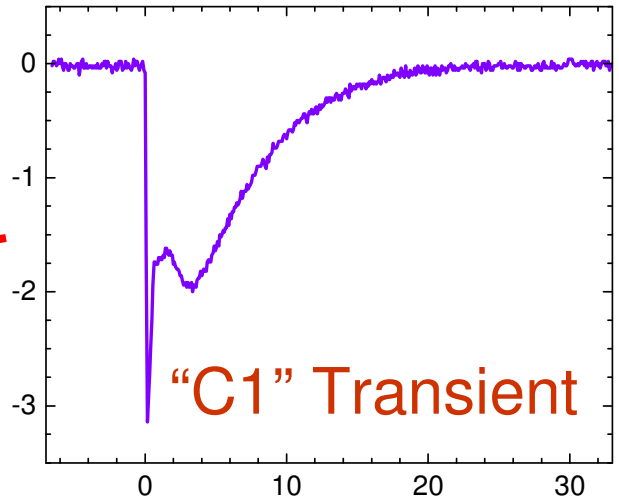


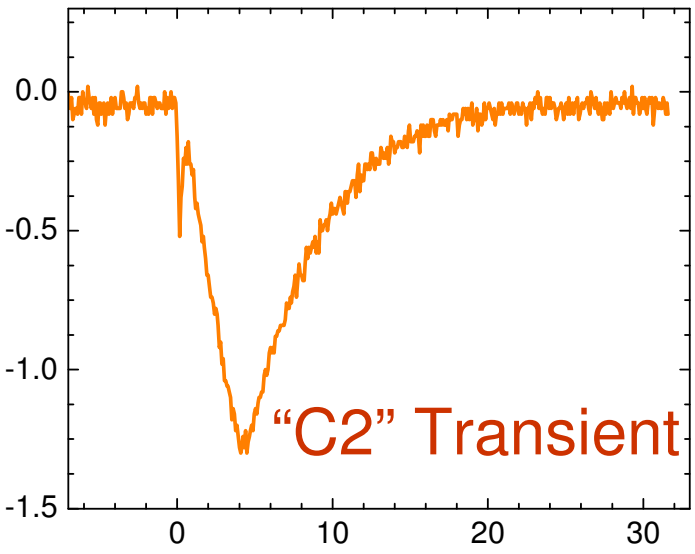


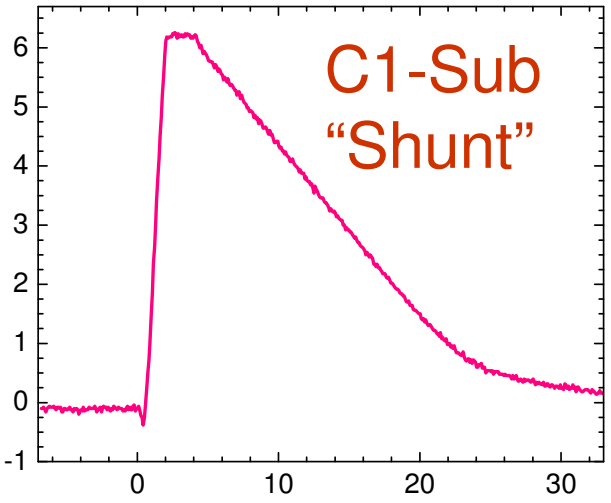


LM124 Q20 TPA SET: “Z” Dependence

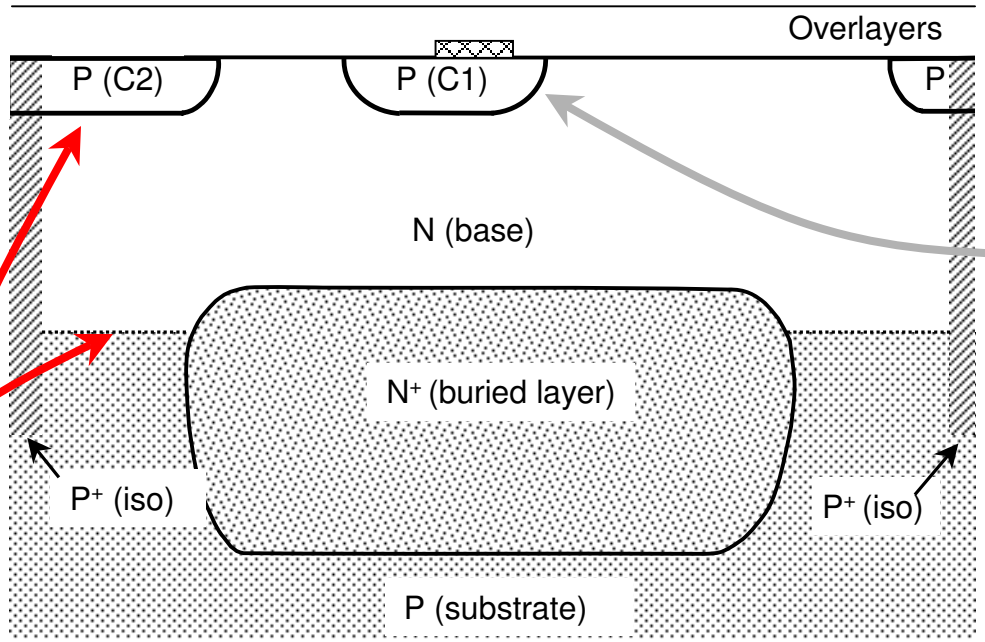


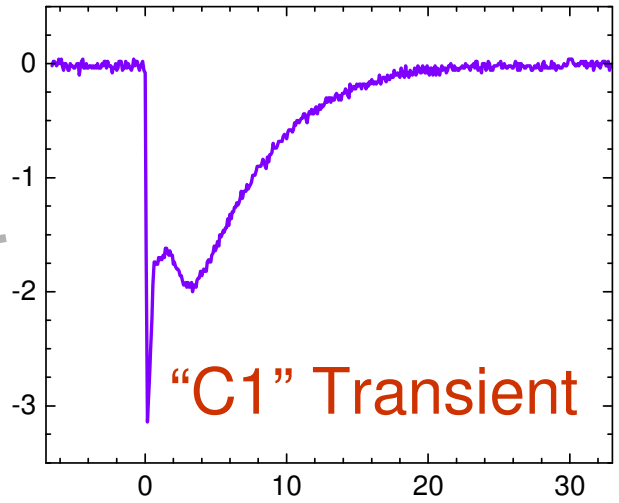


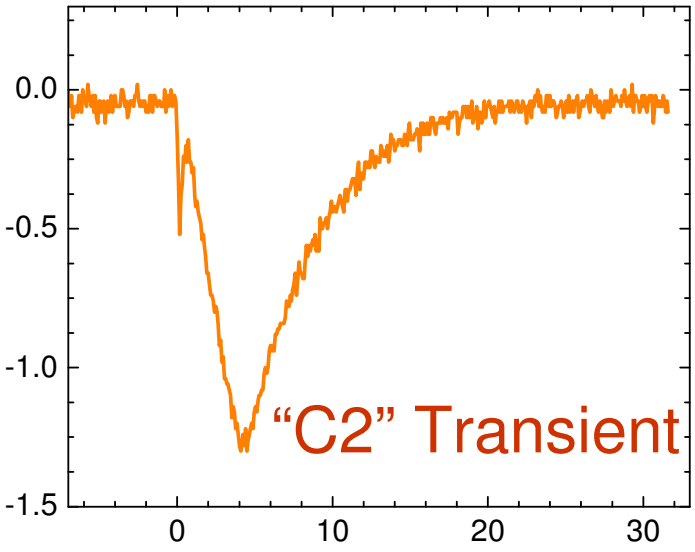


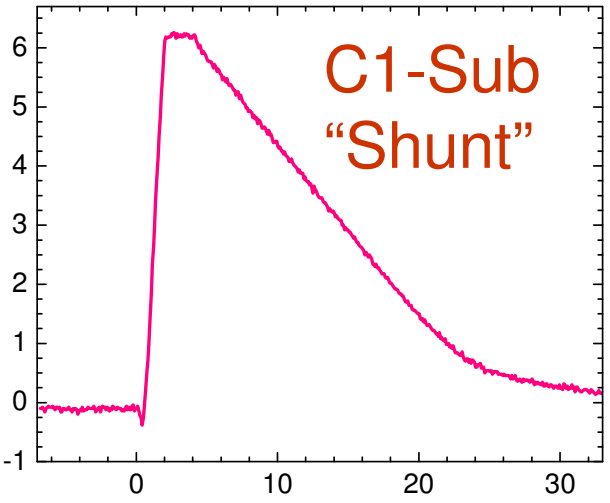


LM124 Q20 TPA SET: “Z” Dependence

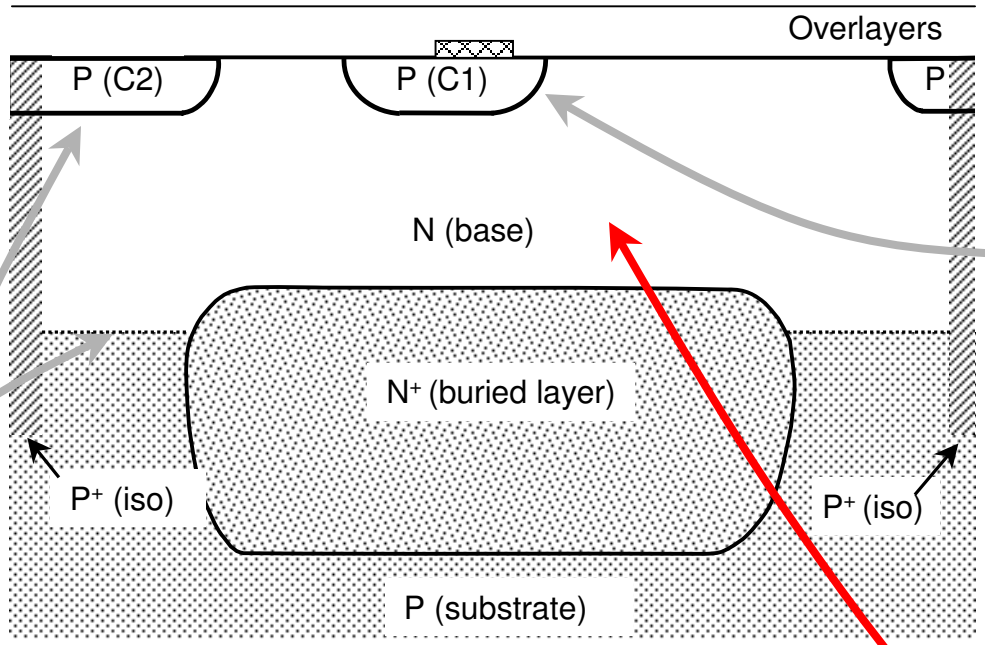


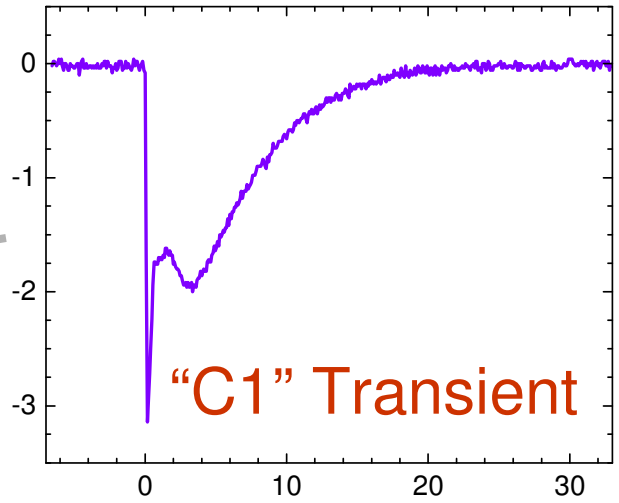


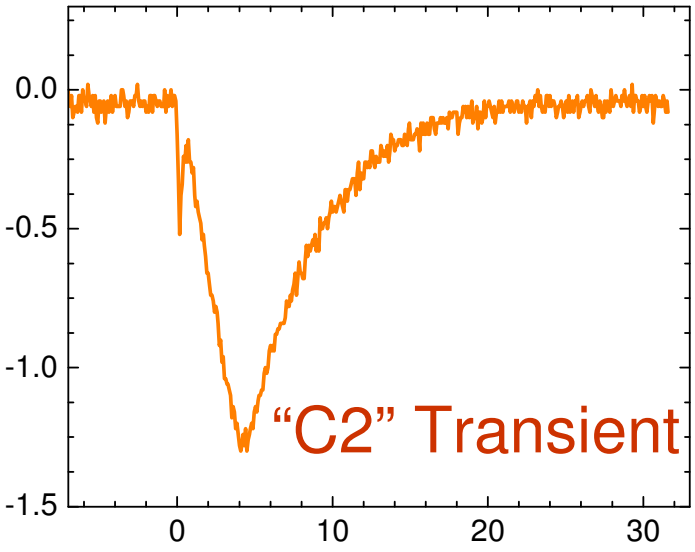


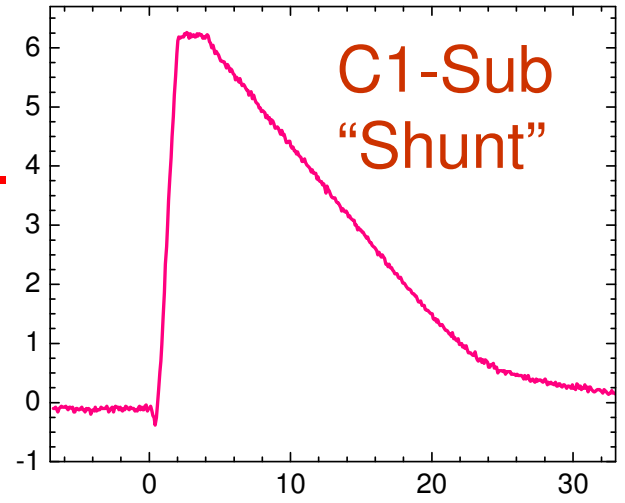


LM124 Q20 TPA SET: “Z” Dependence

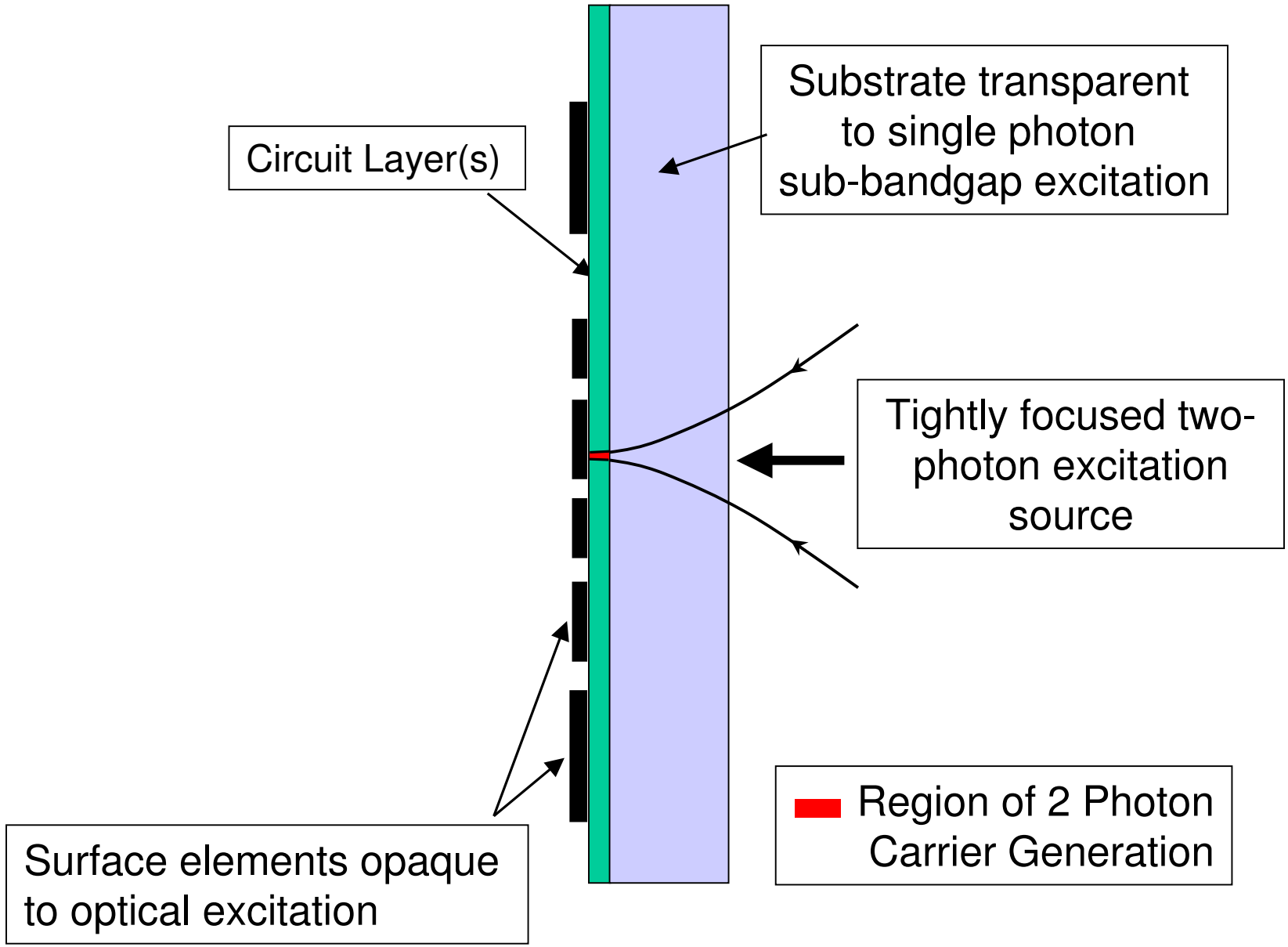




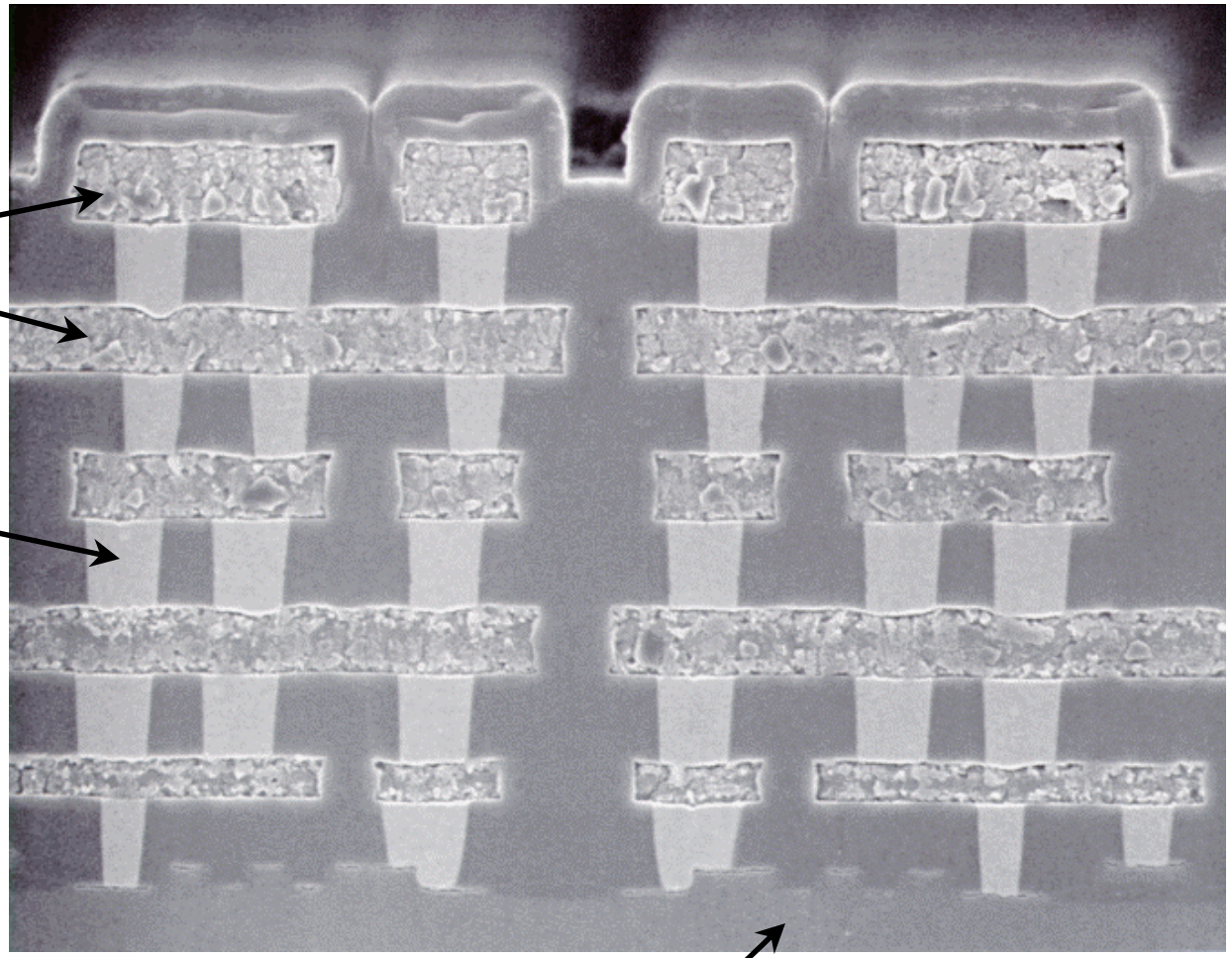




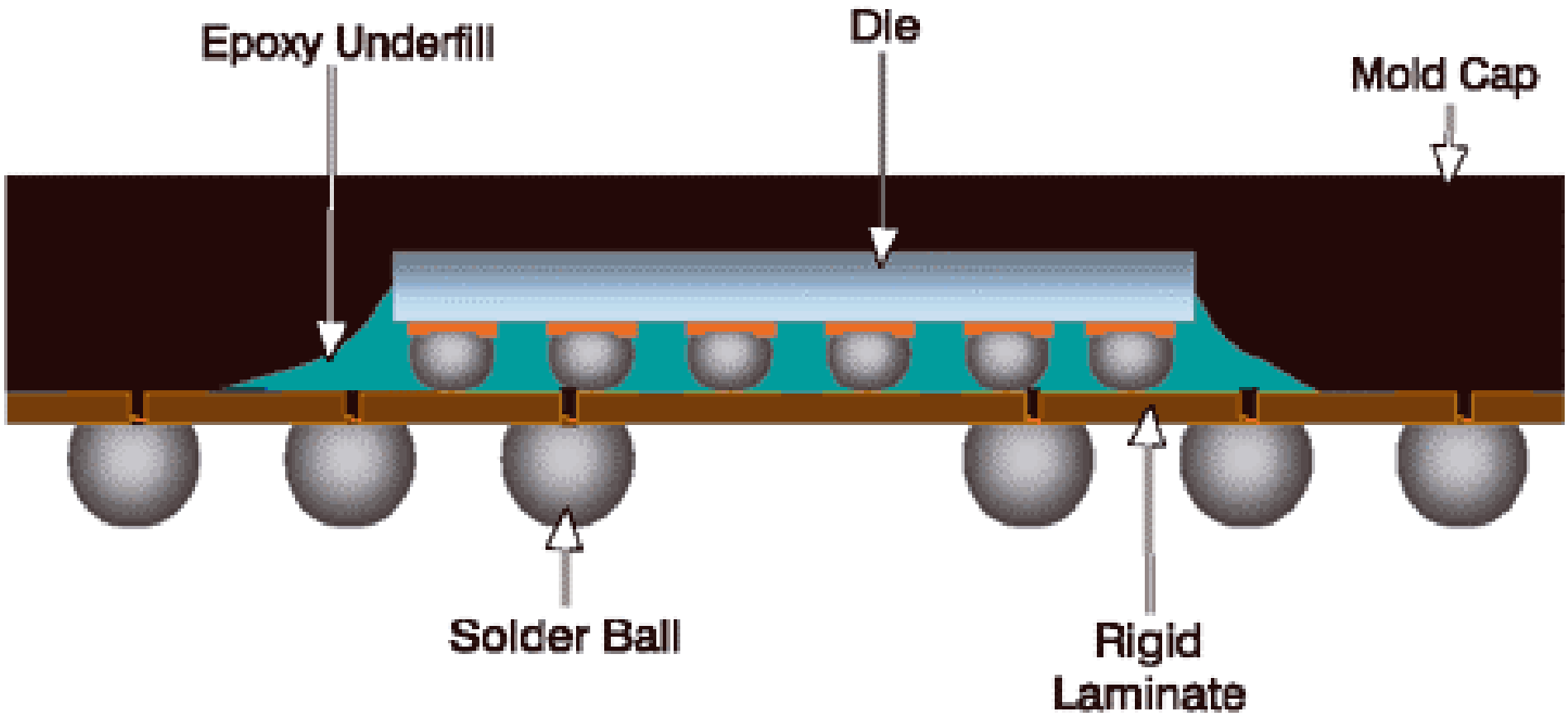
Backside "Through-Wafer" TPA Illumination



Cross Section of Modern Device



Schematic Flip Chip Cross Section



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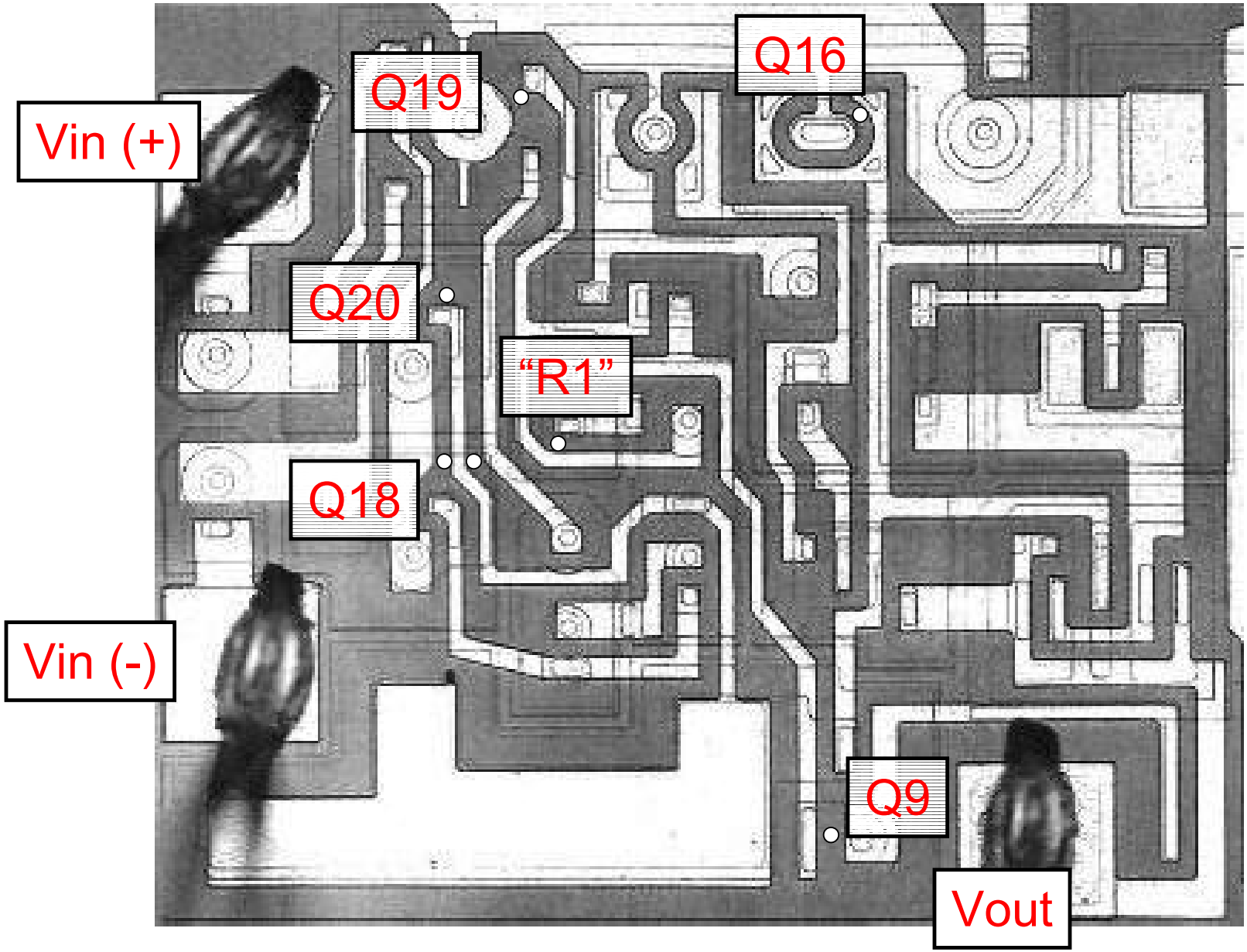
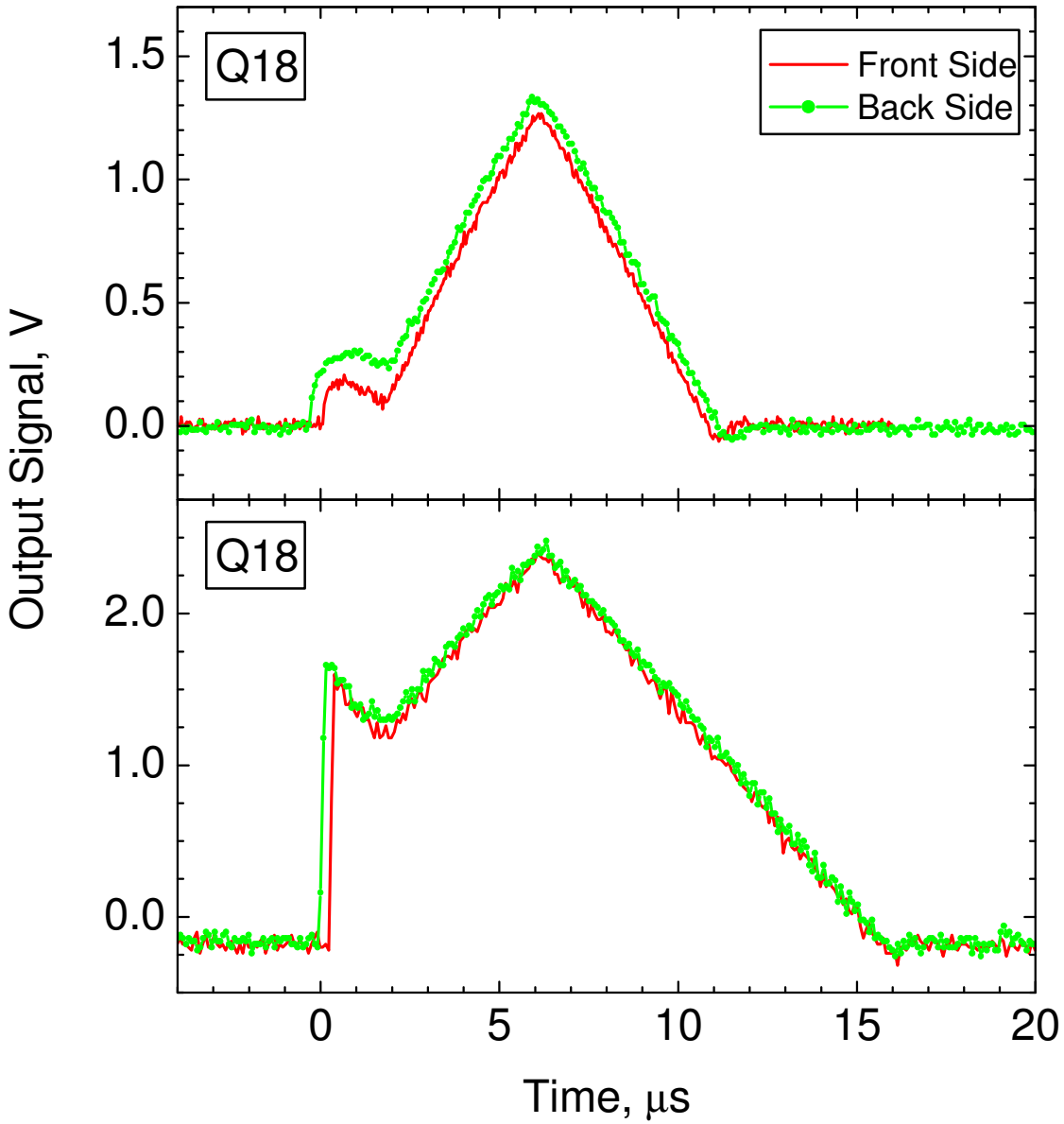
Backside "Through-Wafer" TPA Illumination

LM124 Operational Amplifier



Backside "Through-Wafer" TPA Illumination

LM124 Operational Amplifier



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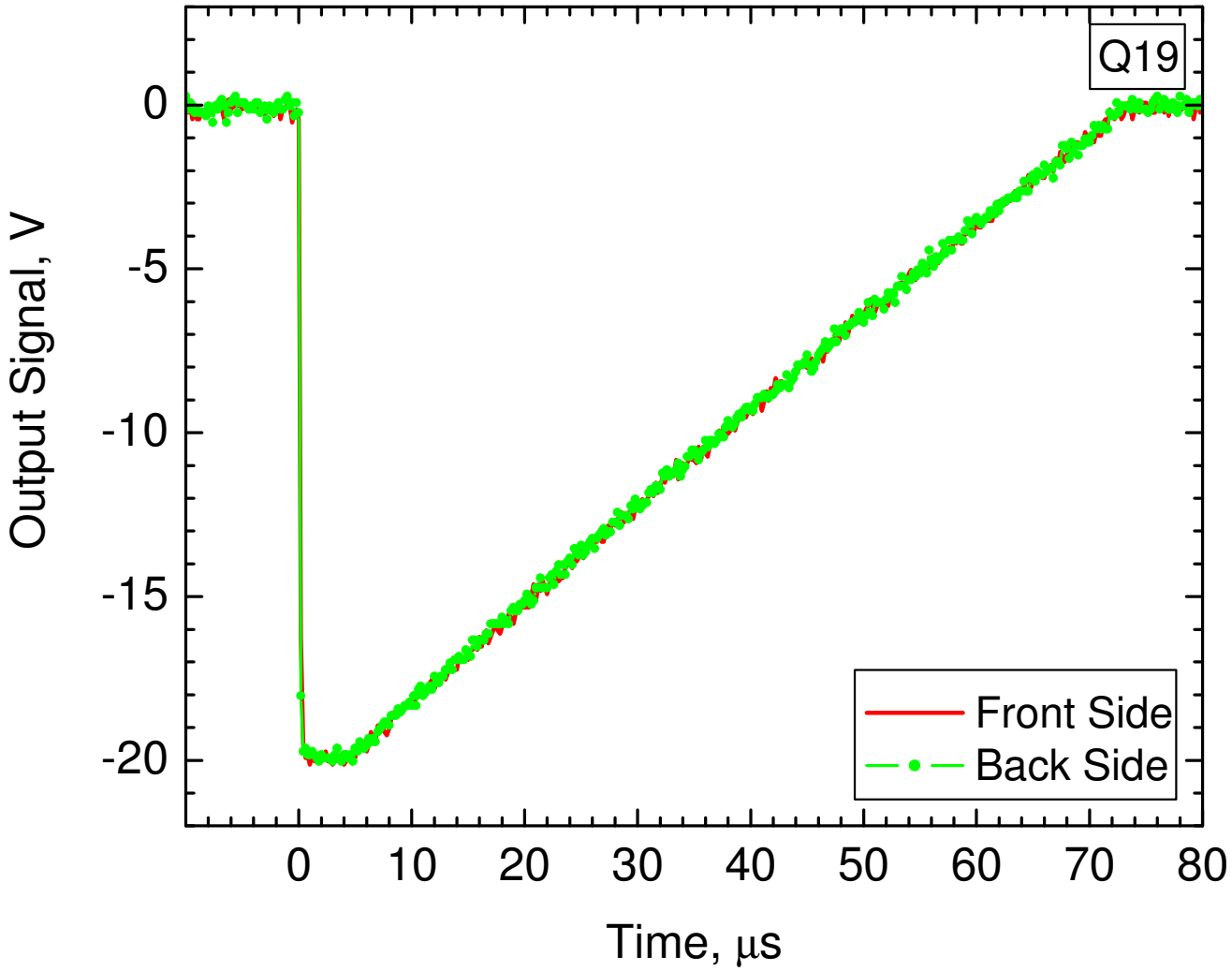
LM124 Operational Amplifier



DTRA Defense Threat Reduction Agency

NRL

Backside "Through-Wafer" TPA Illumination
SEU in Flip Chip SRAM

- Issues
  - through-wafer imaging
    - InGaAs FPA
  - highly-doped substrate
    - linear loss from free-carrier absorption
    - attenuates IR beam
    - attenuates illumination light
    - wafer *thinned* to minimize absorption
- *Results*: SEUs successfully injected in SRAM by TPA at well characterized locations

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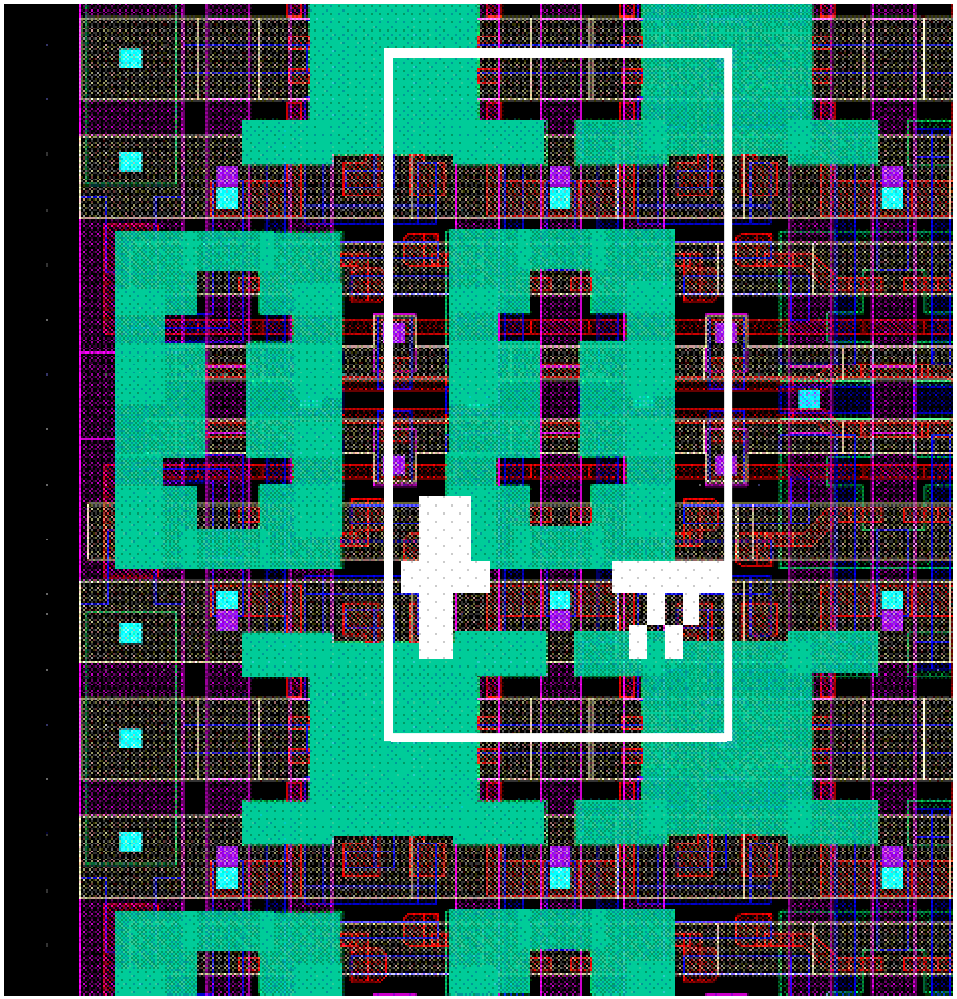
Backside "Through-Wafer" TPA Illumination
SEU in Flip Chip SRAM Test Structure

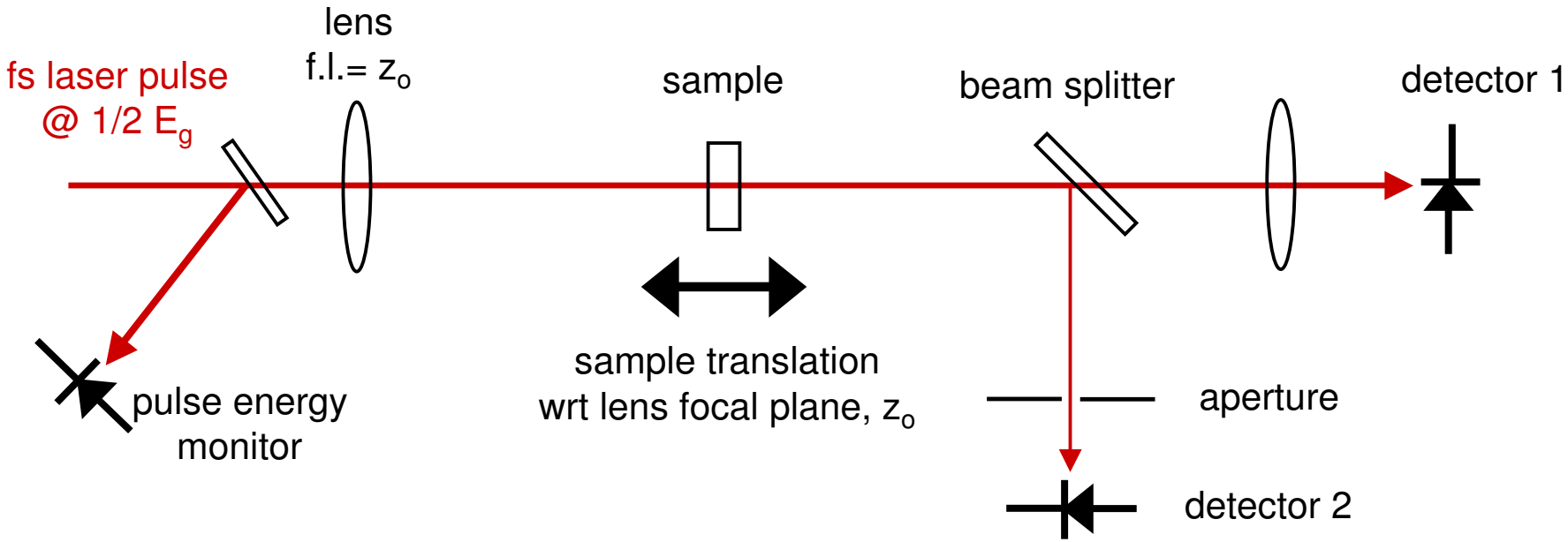
2D SEU Map



Conclusions

- The two-photon absorption method represents a novel approach to SEE evaluation with unique capabilities not exhibited by other techniques
- The present work demonstrates the utility of the nonlinear-optical TPA approach as a method for injecting carriers into the active regions of devices using both top-side and through-wafer, backside irradiation
- The use of backside irradiation eliminates interference from the metallization layers, and circumvents many of the issues associated with testing flip-chip-mounted parts
- The first experimental demonstrations of the through-wafer, backside, two-photon-induced single-event effects technique are presented

Nonlinear Optical Measurements: Z-scans

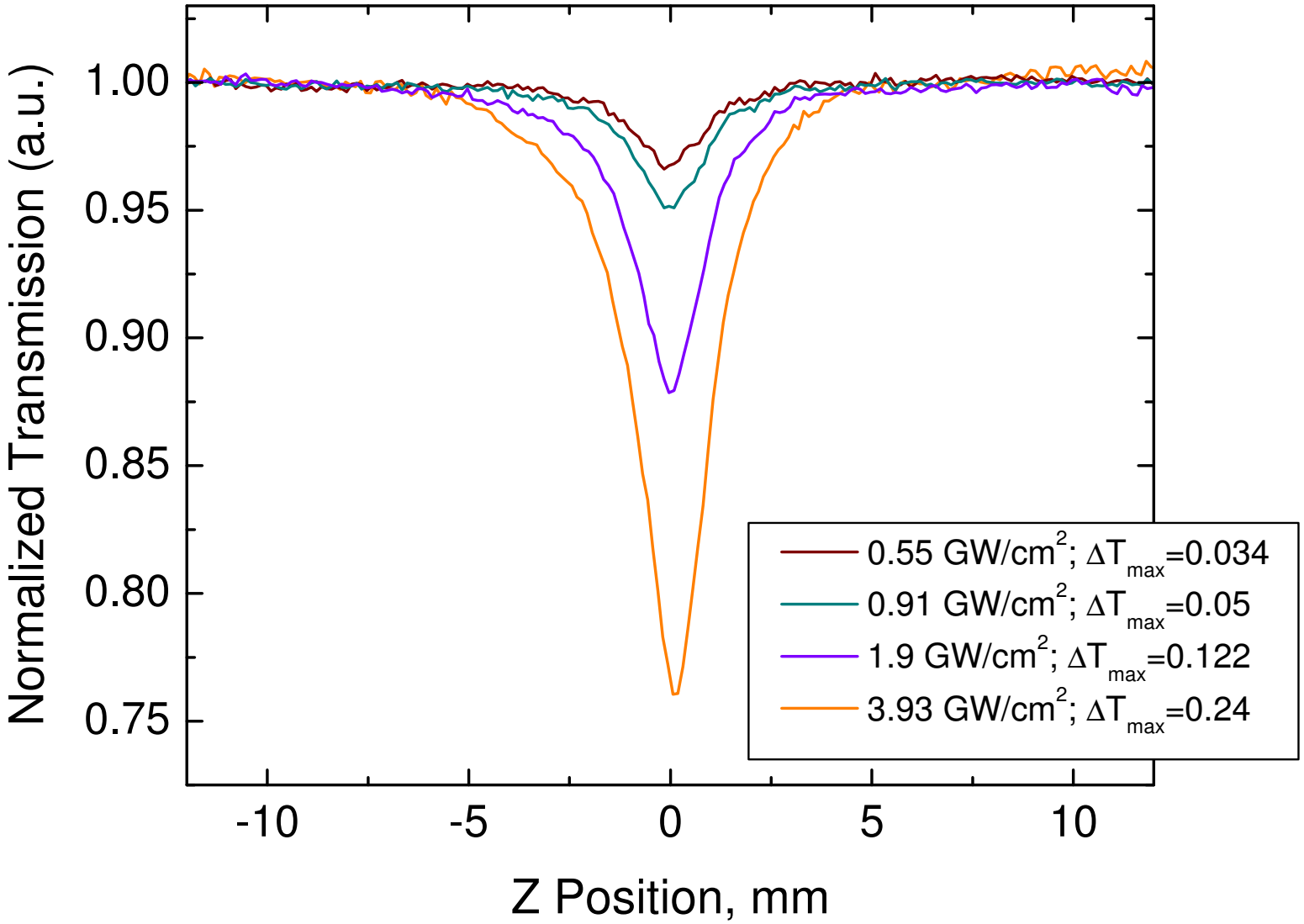


Ultrashort laser pulse induces nonlinear lensing in sample:

$$\Delta n(r,t) = n_2 I(r,z)$$

Open Aperture Z-Scan Measurement of TPA

Antimony-Doped Silicon (0.02 Ω-cm)



Open Aperture Z-Scan Measurement of TPA

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